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ELECTRICALLY OPERATED TOOLS.—[See page 296.]

Properties of Water and Ice at High Pressures—II*

Five Different Kinds of Ice Discovered

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Concluded from Scientific American Supplement No. 2000, Page 281, May 2, 1914

After the completion of the preliminary work, in which the methods of producing and accurately measuring high pressures had been decided upon, there were opened a number of interesting fields for investigation, and the question arose as to which field to choose in order to obtain the most significant results. It was at once seen that nearly any kind of measurement would involve, as one of the data needed in discussing the bearing of the results, a knowledge of the change of volume of the substance under pressure, with the pressure, and it was decided, therefore, to obtain, first of all, measurements of such changes or compressibilities.

The first substance chosen for the measurement of compressibility was water, chiefly as it is so common a substance, and because many measurements had been made on it previously at low pressures. In this connection a method was devised by which the compressibility of water could be measured up to 12,000 kilogrammes. It will be well to mention here that water is not absolutely incompressible, as is commonly supposed, but that its volume may be very appreciably diminished by the application of sufficiently high pressures. Under 12,000 atmospheres a decrease of volume of about 20 per cent is produced. The measurements of the compressibility of water by the new method were found to be satisfactory at comparatively low pressures, but at higher pressures there were, quite frequently, discrepancies which could not be explained by errors in the apparatus. The temperature of these measurements was that of the room, about 20 deg. Cent.

Apparently the only possible explanation of the irregularities shown was that the water had been frozen by the high pressure, so that measurements of the volume at high pressures were sometimes being made on the liquid and sometimes on the solid. This explanation, if it were the true one, indicated a very remarkable state of affairs, as the application of ordinary pressures to ice causes it to melt. One would expect to be able to melt ice by high pressure, therefore, and not to freeze water. However, the above explanation does not seem so utterly improbable as this reasoning would suggest, when there is taken into consideration some remarkable work performed by Prof. Tammann at Göttingen. Prof. Tammann found that when ice is subjected to pressure at temperatures lower than —22 deg. Cent. it is no longer possible to cause it to melt, but that, instead, it changes in form, passing over to another kind of ice which is more dense than water, instead of less dense, as is ice at atmospheric pressure. The pressure needed to produce this second kind of ice is about 2,200 kilogrammes per square centimeter. These two forms of ice are comparable to the two forms of carbon, coal and diamonds, with this difference, however: this new kind of ice changes to ordinary ice just as soon as the pressure on it is removed, in the same way that ordinary ice will change into water when a sufficient amount of heat is applied. Tammann succeeded in discovering two new kinds of ice, each denser than water.

The discoveries of Tammann materially assist in providing an explanation of the irregularities found in the compressibility measurements referred to above, since, if the ice is denser than water, it may be expected that its freezing point will be raised as the pressure is increased, according to the following reasoning: First, consider ordinary ice, that is, ice at atmospheric pressure; apply pressure to it, and its volume decreases slightly. But if the ice melts, its volume also decreases. Consequently, when pressure is applied, the ice is being helped to melt, so that ice under pressure will melt at a slightly lower temperature than does ice on which there is no pressure. In the same way, if the volume of the ice be less than the volume of the water, and pressure be applied to the water, its volume would be decreased, so that water under high pressure is frozen more easily than water at atmospheric pressure. In other words, if the ice is of less density than water, the freezing point is lowered by the application of pressure, but if the ice is of greater density than water, the freezing point is raised by pressure.

The application of this proposition to the irregularities mentioned above is immediate. Tammann had discovered that at high pressures there are two modifications of ice, each of which is denser than water. It would be expected that the freezing point of the modified form would be raised by the application of pressure, so that possibly the irregularities could be explained by the freezing of water to this new form of ice at 20 deg. Cent. under the very high pressures reached in this work, which were about five times those reached by Tammann. But the fault in this explanation is that Tammann had predicted from measurements on this new kind of ice that no pressure, however great, could possibly raise the freezing point of water higher than about —17 degrees, and a temperature of +20 deg. Cent. was here being employed. Careful investigation of the whole matter was therefore called for, and special apparatus had to be designed to attack the new problem.

To state that it is possible in the experiments to ascertain whether the water has frozen to ice or not, may appear strange, when it is considered that the ice is inclosed in a cylinder and can never be seen, because as soon as the pressure is removed and the cylinder opened the ice immediately liquefies. As a matter of fact, this cannot be ascertained, except indirectly. When the water freezes to ice, there is a decrease in volume, and this is shown by a drop in pressure. The converse is true when ice melts to water.

In the actual measurements the temperature of the

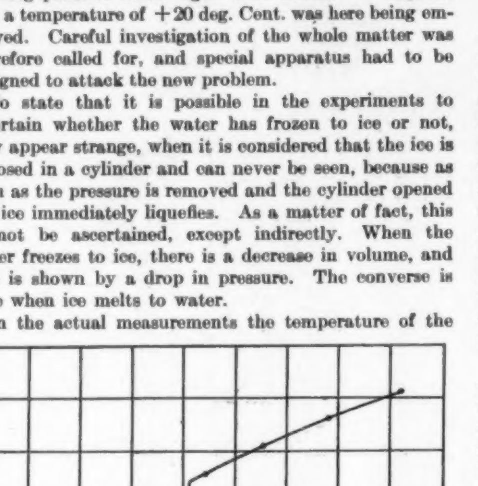


Fig. 4.—Curve showing relation between pressures (abscissæ) and volumes (ordinates) of water. The straight vertical part of the curve corresponds to the process of freezing from liquid to solid.

water was kept constant. In order to increase the pressure, the piston was pushed into the cylinder, the distance being measured, and the displacement of the piston plotted against the increase of pressure produced. The pressure at first increased regularly as the displacement, but when the pressure reached a value high enough to freeze the water at the particular temperature of the experiment, the volume suddenly decreased without the pressure rising at all. Then, after freezing was completed so that there was only solid ice in the apparatus, the pressure resumed its regular rise with the displacement. This is illustrated by the curve in Fig. 4, in which the abscissæ represent pressures and the ordinates volumes.

The pressure at which the piston falls into the cylinder without producing a rise of pressure (that is, the vertical part of the curve in Fig. 4) is the pressure at which the water freezes to ice at the particular temperature of the experiment. For every temperature, the pressure at which the water freezes is different. When the ice is denser than water, the freezing temperature increases as the pressure increases. In this way it is possible to find at what pressure water freezes for any given temperature, and so to construct so-called "melting curves."

It will be noted that the method given above, besides determining the pressure at which water freezes at a given temperature, determines another factor. The amount by which the piston is pushed in while the pressure remains constant evidently indicates the change of volume in the water while freezing, from which the difference in volume between the water and the ice can be computed. If we know the density of the water, we can calculate immediately the density of the ice. These are important data, since if both the temperature and pressure at which the ice melts are known, together with the change of volume, the amount of heat necessary to melt the ice can also be computed.

The method of experiment outlined above is not original with the writer, and has, in fact, been employed by many other previous experimenters. The only important difference is that the new packing which I devised makes it possible to obtain a piston which has absolutely no leak, even at the highest pressures, and so renders possible accurate measurements of the change of volume. This has, I believe, not been possible before. In all previous experiments there has been some leakage around the piston, which made it impossible to obtain accurate measurements of the change of volume.

To return now to the compressibility measurements and the discrepancies found at high pressures, the application of the present method of experiment to the study of water showed that there did exist a new variety of ice at the high pressures, as had been suspected. It was found that the new variety of ice was not one of those two kinds previously discovered by Tammann, but was, instead, considerably denser than either of the varieties found by him. In addition to this new kind, which is stable at high temperatures and pressures, I discovered still another kind, not previously known, intermediate between the new high-pressure ice and the two varieties found by Tammann, making four varieties of ice denser than water. There are, therefore, in all, at least five different kinds of ice, only one of which we are ordinarily familiar with.

Fig. 5 shows more clearly the relation between these different kinds of ice. It will be noted that in this figure there are five regions, numbered according to the kind of ice to be found within the region. Thus, for example, if in an experiment the pressure be raised to 10,000 or 10^4 kilogrammes and the temperature maintained at 0 degree, these corresponding to the point 10, 0 on the diagram, the water substance will be found to exist in the form of ice VI. Or again, if the pressure is 2,000 or 2×10^3 kilogrammes, and the temperature +20 degrees (point on the diagram 2, 20), then the water substance is in the form of ordinary liquid water; or, thirdly, if the pressure is 1,000 or 10^3 kilogrammes, and the temperature —20 degrees (point on the diagram 1, —20), then the water substance is in the form of ice I, the form we are ordinarily familiar with.

On any of the boundary lines of the regions in Fig. 5 the two adjacent forms of water substance are in equilibrium with each other, but if the state of the mass be changed slightly so that it is represented by a point within either of the regions, the kind of ice in that region prevails and the other disappears. Thus, let us suppose that there is ordinary ice, ice I, at say —10 degrees and atmospheric pressure, in the apparatus at the beginning of an experiment, then if the pressure be increased (keeping the temperature constant at —10 degrees) at about 1,000 or 10^3 kilogrammes (point 1, —10), the ice melts to water. But if now we continue to increase the pressure, at about 4,400 or 4.4×10^3 kilogrammes (point 4.4, —10), the liquid water freezes again to a new kind of ice, ice V, which is denser than water. If we still further increase the pressure, at about 6,300 or 6.3×10^3 kilogrammes (point 6.3, —10), the ice V suddenly changes to ice VI, the volume again decreasing during the change. Or, if we commence at atmospheric pressure and —30 degrees (point 0, —30), and increase the pressure, we first change ice I (ordinary ice) into ice III, then, on still further increasing the pressure, ice III changes to ice II; on further increase, II changes to V, and finally V changes to VI. The high temperature to which the curve between ice VI and the liquid runs is of interest: by the application of 20,000 or 20×10^3 kilogrammes we may freeze water, although it is nearly boiling hot.

The four varieties of ice denser than water have several interesting properties. Thus it will be noticed in Fig. 5 that the curve separating region VI from the region of the liquid, L, is prolonged into the region where V is stable. The interpretation of this is that it does not always hold that when one of the modifications is carried into a region in which another variety exists as the stable form, the unstable form will immediately disappear; thus it is possible to carry either liquid water or ice VI into the region in which V is the stable form, and to maintain it there for a considerable time without the change to V taking place. We are all familiar with a similar property shown by liquid water at atmospheric pressure; it is possible to cool liquid water considerably below 0 degree without the water freezing, particularly if care is taken not to subject the water to any mechanical disturbance. The fact that liquid water and ice VI may both exist in the region in which V is the stable form was the cause of considerable trouble during the first experiments, when it had not yet been established that there really was another form of ice, ice V. On the

* Abstract of paper presented at the meeting of the Section of Physics and Chemistry, and published in the *Journal of the Franklin Institute*.

melting curve of ice VI below 0 degree a number of irregularities were found for which the only explanation seemed to be that there was a new variety of ice. At first, however, the experiments could not be repeated, and it was only after some time that it was discovered that an apparently very unessential variation was sufficient to determine whether VI or V would freeze out of water at temperatures a little below 0 degree. If the experiment was performed with the water contained in a glass bulb, ice V would freeze out of the liquid, but if the water was enclosed in a steel bulb, then ice VI almost always froze out of the water. The presence of a few splinters of glass was sufficient to ensure the appearance of V instead of VI. The explanation of this strange phenomenon has not yet been found. The phenomenon is simply an illustration of a fact with which chemists have been familiar for a long time; namely, that if a substance is capable of existence in two or more forms, it usually holds that the more unstable form appears first instead of the stable form.

There is one exception to the statement that it is possible to carry one modification into the region of another and maintain it stable. None of the varieties of ice can be carried into the region in which liquid water is the stable form without the solid melting. It seems to be impossible to superheat a solid with respect to a liquid, although it is almost always possible to subcool a liquid with respect to a solid. This rule has been hitherto found to be of practically universal application at atmospheric pressure, and it is here seen to apply at high pressures also. Ice II behaves in a similar way with respect to ice III. Ice II may not be superheated appreciably with respect to ice III, but III may be very considerably subcooled with respect to II. That is, III behaves with respect to II as if it were a liquid, although we know, by direct proof, that III is really a solid.

The manner in which one ice changes into another is truly remarkable. We know that water freezes slowly or that ice melts slowly, but some of these kinds of ice will change into another kind so rapidly that the reaction reminds one of an explosion. For instance, if ice I is changed to ice III at —25 degrees, the reaction takes place so suddenly that it is impossible to follow the change of pressure which takes place after the reaction. On several occasions I have heard of a click in the apparatus when the transformation took place, so rapid was it. Still another remarkable thing is that the effect of temperature on the velocity of the reaction is very great indeed. If ice I is cooled to about —50 degrees, the reaction occurs so slowly that it takes hours for its completion. Similar behavior is found also on the curves III-V and V-VI; the reaction from one solid form to another is very rapid indeed at temperatures near the melting temperature, but as the temperature is reduced the speed of the reaction becomes very much less. This is the reason that the curves separating the domains of the different kinds of ice could not be followed to lower temperatures than are shown in the diagram. At lower temperatures the reaction becomes so very slow that it would have taken days to obtain a single point. It is to be expected that the curves separating II and V and V from VI will continue to run to lower temperatures, that they will finally meet, and that from the point of intersection a new equilibrium curve, the curve between II and VI, will start. The point at which any three curves meet in the diagram is called a triple point. It will be noticed from the figure that two curves never meet without a third curve starting from the point of intersection of the other two. This is always true, provided that on two of the curves there is a phase in common; it may be proved mathematically that such is the case, but to prove this here would take us too far afield.

The fact that ice I gives place to ice II at a certain pressure has one practical application. We have often heard of the immense pressures developed when water is allowed to freeze in a closed vessel. Burst water pipes are a familiar example of this, and there are also well-known experiments in which cannon balls have been split open by freezing water. It is of interest to inquire how much pressure might be reached in this way. The diagram furnishes an answer to the question, as it shows that if the pressure on the ice during freezing should rise to much over 2,000 or 2×10^3 kilogrammes, corresponding to 30,000 pounds per square inch, the ordinary ice would change to ice III, which has a much less volume, so that the ice would tend to shrink and the rise of pressure would be arrested. Thirty thousand pounds per square inch is, therefore, the highest pressure that can be obtained by freezing water in a closed space.

It may be of interest to give a rough idea of the difference of volume between the different forms of ice. To indicate the change of volume accurately, it is necessary to specify the pressure and the temperature at which the change from one variety to the other takes place, because the change of volume depends somewhat on both these factors. Roughly, ordinary ice—ice I—is from 10 to 13.5 per cent less dense than water. Ice III is on the average 3 per cent denser than water, and 20 per cent denser than ice I. Ice II is about 22 per cent higher in density than ice I. Ice V is about 5.5 per cent denser than ice III and perhaps 6 per cent denser than water. Ice VI is 4 per cent denser than ice V and from 9 to 5 per cent denser than water.

The latent heat—that is, the the amount of the heat absorbed when ice melts to water—is about the same for all the varieties denser than water that it is for the ordinary kind. The various modifications of the solid have, however, this remarkable relation to each other; namely, that the one may change to another in a large number of cases without any appreciable transfer of heat. Wherever, in the diagram, there is a transformation curve running vertically, then on that line the one solid form passes to the other without appreciable heat transfer. This fact allows the very sudden change from one solid form to another that has been commented on,

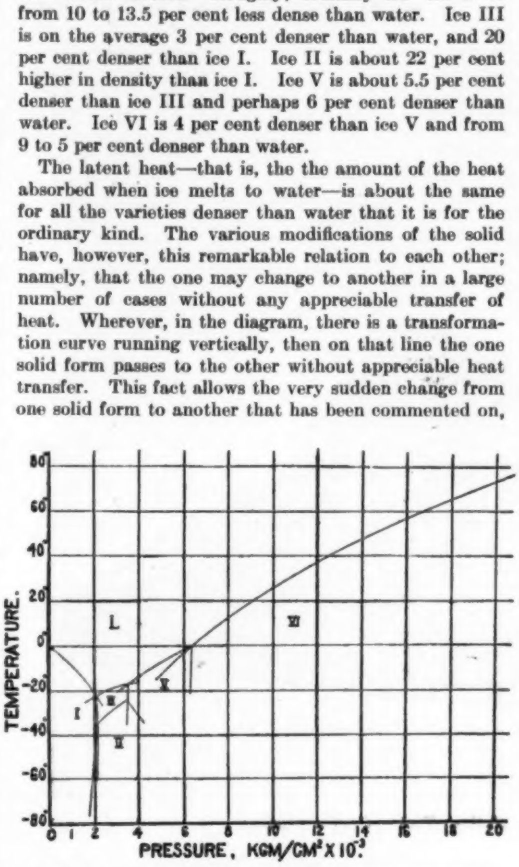


Fig. 5.—The equilibrium diagram between the liquid and the five solid modifications of water.

because if there were any heat of transformation, it would be set free during the reaction, and would have to be conducted away, which would take time. Therefore, the reaction could not run faster than the heat could be conducted away. In those cases in which there is no heat to be conducted away the reaction might be very fast indeed. But the fact that there is no heat of transformation does not explain why the reaction is very rapid; it simply makes a rapid reaction possible, provided that the other factors are favorable. This is shown by the fact that at the lower temperatures on the transformation curves there is still no heat of reaction, but the reaction, nevertheless, runs slowly.

A word as to the possibility of proving that the various new forms of ice that have been described are really solids. All that has been shown in the experiments is that at certain pressures and temperatures there is a sudden change of volume. This must mean a change of some kind in the molecular structure of the substance, but on what ground can it be said that the change is a change to a solid form? May not there conceivably be two modifications of the liquid? The answer is, first, that no substance is known which has two modifications of the liquid, but that many are known which have two solid forms. None of our ideas of the molecular structure of solids or of liquids would lead us to think that two liquid forms of a substance are possible. Secondly, Tammann has given direct experimental proof that the two forms of ice, II and III, are really solid. He did this by cooling the cylinder containing the ice to the temperature of liquid air, and then opening the cylinder after pressure had been relieved, still keeping the temperature at that of liquid air. Of course, as soon as pressure was relieved, the ice II or III, whichever it happened to be, became unstable, but at this low temperature the reaction from the unstable to the stable, or ordinary ice, runs very slowly indeed, so that there was time enough to examine the contents of the cylinder, after opening it, before all the unstable variety had disappeared. It was found that the new substance was indeed a solid, and that as it changed into ordinary ice it increased greatly in volume. Tammann performed this experiment for both the varieties II and III. It might perhaps be possible to repeat the experiment for the other two varieties, V and VI, but the chances of success are very much less, because atmospheric pressure is so much further removed from the equilibrium pressure for these two varieties that the reaction would be expected to run very much more rapidly. What is more, the behavior of these new varieties is in all respects like that of the two varieties which we know to be solid; that is, under some conditions the reaction velocity is much greater than it ever is when a liquid passes to a solid. Also, in some cases when one variety changes to another, enough pressure is exerted on the thin steel vessel containing the ice to rupture it. It is difficult to conceive how a liquid would develop enough pressure to rupture a steel vessel; one would expect instead that it would flow away, relieving the pressure as fast as it was formed. The overwhelming probability from all the evidence is, therefore, that the other two varieties, V and VI, are solid also.

Experiments which I have performed since these experiments on ice show that the ability to exist in more than one solid form is not confined, by any means, to water substance, but is in all probability a quite common property of matter at high pressures. I have found other modifications of six additional substances, several of them having more than two forms. One, ammonium nitrate, has five forms, the same in number as water. I am not aware that any substance has as yet been found with more than five solid forms. The equilibrium diagrams for these different substances do not bear any obvious relation to each other or to water; the diagram would seem to depend to very great degree on the individual properties of each substance.

Finally, as to a possible explanation of why a solid may have more than one form, there are two conceivable hypotheses: One is that the molecules are arranged differently in the different forms—that is, in different space frameworks with different kinds of symmetry, so that the different solids belong to different crystalline systems. The other is that the molecules themselves are different in the different forms. For instance, it may be that when pressure and temperature have passed certain limits, two or more molecules coalesce or associate and henceforth behave as one. Doubtless there will be found instances of both kinds of behavior; one might expect, however, that in the majority of cases the change in form is due to a rearrangement of the molecules, each molecule preserving its individuality. One reason for thinking that this will prove to be the case is that it is difficult to imagine how such exceedingly rapid change from one solid to another is possible if the molecules have to form new bonds with other molecules. The rapidity of reaction suggests rather that the molecules simply snap round on axes from one position of equilibrium to another. There is no way of being certain, however, what is the correct explanation in any special case, but this is a fertile subject for future investigation.

A Working Erosion Model*

To Illustrate the Influence of Vegetation in Checking Erosion

ESSENTIAL FEATURES OF THE MODEL.

A WORKING model showing the processes of erosion on deforested slopes has been a feature of exhibits made by the Forest Service at recent expositions. It shows the working out of the natural phenomena so well, and is so simple and inexpensive to construct, that a description is here given of a similar model which might be erected in schools for the use of classes in nature study, elementary agriculture, and physical geography.

*Circular 17 of the U. S. Department of Agriculture.

The model consists of two hills sloping down into two valleys through which two streams wind in and out through farm land and lead into two lakes at the front of the landscape. (Fig. 1.) Both hills are made of the same kind of soil, that of the region in which the model is erected, but one is covered thickly with twigs, young trees, or shrubs, to simulate a forest, underneath which is a heavy carpet of moss representing the layer of leaves and twigs which covers the ground in the real forest, while the other hill is bare of all vegetation.

By means of a suitable sprinkling device water in the form of rain is made to fall with equal force upon the two hills. On the forested slope its fall is broken by the foliage, and it drops gently upon the moss-covered surface of the ground. The moss and the soil beneath, which is kept soft and porous by the protective cover, quickly absorb the rain and allow it to seep out as clear water farther down the slope, thus forming a mountain stream which flows through a green and fertile valley into a clear lake at the lower end of the model.

On the other slope the rain beating down upon the unprotected and hardened surface washes deep gullies in the hillside, carries the soil into the turbid stream which drains the valley below, and thence into a muddy lake. The erosion on the slope loosens stones, which are carried down upon the valley farms; the silt deposited in the channel of the stream diverts the water, which opens up gullies through the dry land; the main stream is made shallower and wider and often overflows into the fields; islands and silt bars rise in the stream; and deltas are built up in characteristic form at the entrance to the lake.

The erosion processes which work themselves out in this model, the wearing down of the hill, the silting up of the stream bed, the gradual shifting of the course of the stream, the formation of deltas and sand bars in the lake, and the gradual opening up of watercourses through them are all typical of the processes constantly going on in nature, and show strikingly the close relationship between forests and surface formation. It is the same process of erosion on a larger scale which, after the destruction of our forests, causes the removal of the top soil from our slopes, cuts them up into gullies, and deposits sand and gravel upon the fertile alluvial soil of the bottom lands, in storage reservoirs, or in the channels of streams, where it impedes navigation and causes overflow.

While the model is not intended primarily to show more than the erosion processes, it can be used to show also that a forest-covered slope acts as a reservoir in impounding the water and allowing it to seep slowly into the streams, and, on the other hand, that water runs off the surface of a bare slope as soon as it falls, resulting in floods when the precipitation is heavy and in droughts during a dry season. If the sprinkler is stopped and all the water taken out of both of the streams and the lakes, the lake on the forested side will, within a few hours, receive a considerable amount of water as seepage from the wooded hillside, while the other lake will remain practically empty.

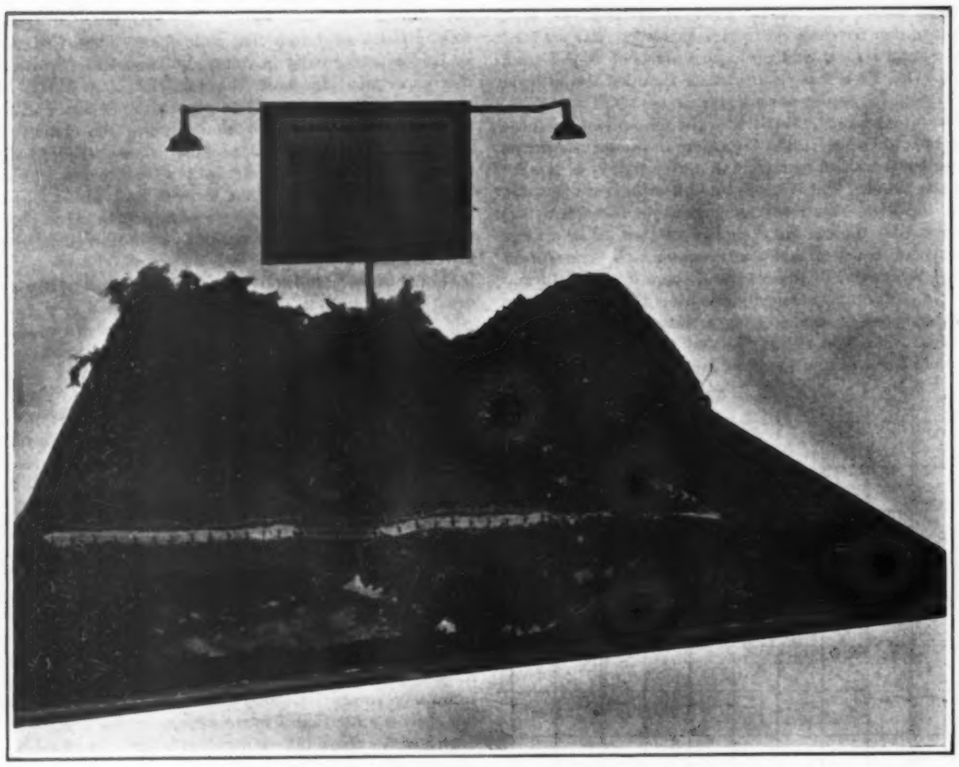


Fig. 1.—This model shows some of the effects of deforestation.

CONSTRUCTION OF THE MODEL.

Convenience may determine the size of the model. It may be as small as 4 feet square, but 7 feet square is probably a better size for working out all of the phenomena. Directions are here given for a model 5 feet square.

Construct a strong tray measuring, on the inside, 5 feet square and about 6 inches deep, with the sides re-enforced with heavy nails so as to resist the warping of the wood when wet. The bottom of the tray should be made of tongued and grooved material running from front to rear and made water-tight with lead paint between the planks and paraffin over the seams. (Fig. 2.) The paraffin should be applied hot and plenty should be used. The rear of the tray might be placed against the wall 2 feet 4 inches from the floor, and the front placed on legs, 2 feet high. This will give a sufficient slant for good drainage. (Fig. 3.)

Now fill the tray within about 2 inches of the top with rubble and earth, with the general slant of the surface toward the center of the front of the tray. Slight depressions should be made in the soil, as foundations for the two streams, and two large depressions should be left in the front corners for the lakes. Drainage of these lakes should be provided for by shallow channels from their surfaces to a drainpipe in the middle of the front of the tray or in some other suitable place.

Next, place from 1 to 2 inches of mortar, consisting of about one part cement and two parts sand, over the entire surface. The mortar should be stiff enough to maintain its shape. Work in the stream beds and the lake depressions before the mortar sets, taking care that the outlets of the lakes are only slightly lower than the intakes at the mouths of the streams. Of course, the more irregular the stream beds are made, the more natural will they appear when finished. Little sinuses, swimming holes, obstacles, and inequalities in elevation to create waterfalls, and similar natural touches will add attractiveness. In applying the mortar care should be taken to retain the general direction of the slant toward the center of the front of the model. Let the mortar dry out for several days, then paint the surface with hot paraffin and burn in the paraffin with a plumber's hand furnace or Bunsen burner. The model should now be waterproof, but it is safer to run a gutter along the front to receive the drippings. (Fig. 4.) The drain from the surfaces of the lakes should also be directed into this gutter, which should empty into a waste pipe.

When the mortar is hard, erect a mound of earth on each of the rear corners of the model, about 1½ feet in height, and so arranged that the front slope of each drains into one of the streams. The hills may be made to appear as two peaks, with a depression between them. Cover one of the mounds thoroughly and thickly with moss, which can be gathered in the woods or purchased by the sack from a florist, and through this moss stick small twigs or trimmings of hedges to represent a forest. Cedar, arbor vitæ, or juniper twigs prove most satisfactory. Stretches of nearly level land should extend from the bases of the hills to the lakes. The land below the forested hill should be covered with a thin layer of top soil furrowed to represent cultivated fields. The parts of these fields adjacent to the stream and lake should be protected from washing by moss and shrubbery.

A double sprinkler should send with moderate force an equal rainlike spray over each hill. The spray should strike each hill in such a way that all the water will be drained into the corresponding stream. No water should flow down the rear slopes of the hills. One kind of sprinkler is made as follows: A water pipe is run up the wall behind the model to about 1½ feet higher than the summits of the hills. To the upper end of this pipe a "T" is attached, the arms of which run out about 1¼ feet on each side, and from the ends of these arms pipes terminating in sprinklers are run forward so as to bring the spray upon the proper parts of the slopes. A stopcock should be near at hand, so that the force of the water can be easily regulated within sight of the model. Rubber hose might be substituted for both the supply and the drainpipes and would reduce the cost. Baking pans perforated with a nail may be used as sprinklers. Great care should be taken to have the entire surface of the forested hill upon which water falls protected with moss, so that the soil cannot be washed away. The water coming from the forested hill will be muddy at first, but will clear after running for a few minutes, and the mud in the water in the lake will soon settle. Erosion will set in upon the deforested hill and the land below as soon as the water is turned on.

The drain should be large and should be protected by a screen or trap so that pieces of leaves and moss cannot get into it. A spiral of wire inserted in the upper end of the pipe will suffice. It is advisable also to have the water from the muddy lake pass through a clump of moss or other close sieve, to clear the water of some of the silt before it passes into the drainpipe.

White sand and pebbles and small goldfish or turtles in the clear lake will add another touch of realism and bring out the clearness of the water. Other ideas to add to the picturesqueness and instructiveness of the model can be worked in, such as a road running through the fields, bridges across the streams, and a little farmhouse or barn appropriately placed. The bridge across

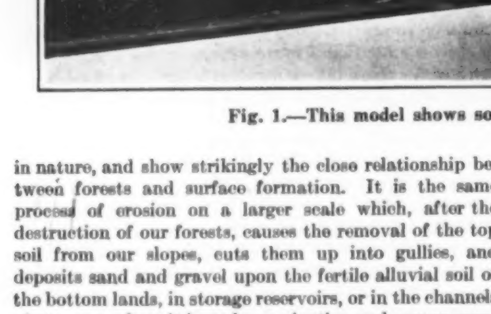


Fig. 2.—Top plan of model.

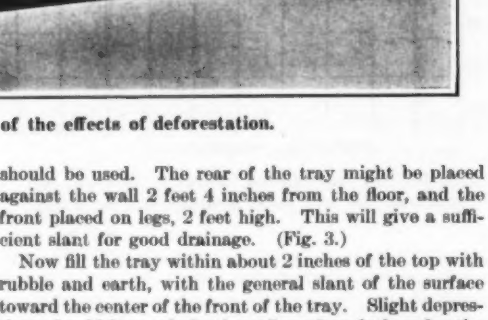


Fig. 3.—Vertical section of model.

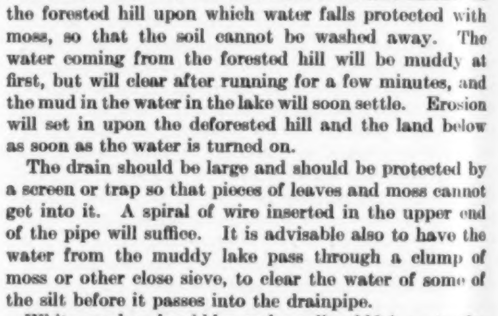


Fig. 4.—Front elevation of model.

the muddy stream can be represented as damaged by floods, and the road on that side of the model, muddy and deeply furrowed.

MATERIALS FOR A MODEL 5 FEET SQUARE.

Lumber:

60 linear feet, 5 inches by 7/8 inch tongued and grooved flooring.

53 linear feet, 2 inches by 4 inches.

21 linear feet, 1 1/4 inches by 8 inches.

Other material:

1 bag of cement.

2 bags of sand.

1 barrel of rubble or small rocks.

5 pounds paraffin.

2 square yards of moss.

1 peck of top soil.

1 bundle of twigs or cuttings.

1 piece, 5 feet long, of 3/4-inch iron pipe, both ends threaded.[1]

1 piece, 5 inches long, of 1-inch iron pipe, not threaded.[1]

4 pieces, each 1 1/4 feet long, of 3/4-inch iron pipe, both ends threaded.[1]

2 single 3/4-inch elbows.[1]

1 3/4-inch "T."[1]

2 sprinklers, similar to illustration (figs. 2 and 3.)[1]

1 stopcock.

1 zinc or tin gutter 5 1/2 feet long.

Pipe or hose to connect supply and drain with model.

[1] Other material may be substituted to suit a different style of contrivance.

The Research Chemist and the Textile Industry*

By W. P. Dreaper

The textile industry of Great Britain shows a gross value amounting to the considerable total of £333,000,000; materials to the value of £235,000,000 were used in their manufacture; and 1,253,000 persons were employed in their manipulation. The power used amounted to 1,987,000 horse-power, and 77 per cent of the firms engaged in their work made a return that they had used during the same period £8,137,000 worth of coal. These figures indicate that there must be under modern conditions an ever-increasing call for research chemists in this industry. If the standard that one chemist is required for every 2,000 persons employed in the textile industry were set up, there would be room for no fewer than 620 highly trained chemists, who would each be dealing with an "average gross output" of the value of more than £500,000 per annum.

When it is remembered that a Continental combine in the aniline-dye industry employs more than 600 chemists, the above estimate of ultimate requirements cannot be considered unreasonable. The effect of this army of chemists working in the interests of the textile industry would naturally lead to astonishing developments and to considerable improvements in detail.

The student who enters a works on the research side, after having received a university education (or having equivalent qualifications), will, undoubtedly, possess a knowledge of chemistry which will rank as an immediate asset.

In addition to this knowledge of theory, the student will make immediate use of any experience he may have gained in ordinary analytical operations. It will often be necessary to devise new methods of analysis, or, at least, modify old ones, before they can be utilized in industrial investigation. A knowledge of the principles which underlie such work is, therefore, a very necessary equipment for the young investigator. This also involves a training which has a special value to those entering this, and most other industries. In many cases, work will rest on the borderland of industrial research, where the actual analysis of certain products can replace actual experiment in very few cases. It is the latter which counts. The former is generally of secondary value.

The research chemist will probably enter the works at an early age. If he has finished his college course at twenty, a year or two of teaching work will do no harm. It will consolidate his knowledge of theory under the stress of imparting it to others. Better still, if it is possible to determine, at that stage, the direction of his future work, he may engage in a post-graduate course of research. The actual time of coming in contact with works conditions should not be delayed beyond the age of twenty-two years, for the mind must be capable of readily adjusting itself to industrial conditions, which are naturally different from those surrounding the student in a college laboratory.[1]

The introduction of a time factor in its relation to cost of production will alone have a great influence. Work in the factory may be practically continuous in its operation. The young chemist will, therefore, quickly realize that he has to deal with entirely new conditions. These will at once claim his interest by reason of their novelty and importance. He will soon be engaged in the attempt to control, or modify, operations proceeding

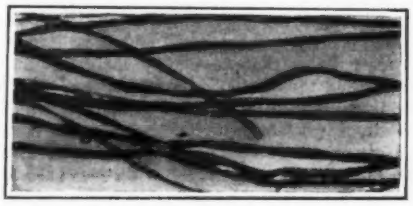


Fig. 1.—Cotton fibers (× 100).

on a scale possibly measured in tons, or thousands of yards.

The raw material will enter at one end of the factory. At the other end, it will leave in a more or less "finished" state. This operation may, in some cases, take months to complete, during which time the material may be

Fig. 2.—Cotton fibers after mercerizing under tension (× 100).

subjected to innumerable processes which may possibly modify both its physical and chemical properties. The chemist will endeavor to understand, and so control, these operations that during transit through the works, material may receive a minimum of treatment to produce a maximum effect; for this generally means satisfactory working conditions and low cost of production.

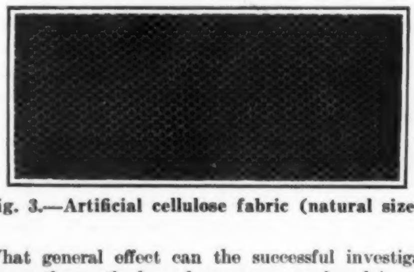


Fig. 3.—Artificial cellulose fabric (natural size).

What general effect can the successful investigator have on the methods and processes employed in work of this nature? He must aim at a position under which determining methods of working are being constantly modified in detail; or even in nature. Under the most successful conditions he may, in time, find himself working three years in advance of those who are not taking full advantage of modern methods of investigation. It is difficult for an industrial chemist to hide from his experienced rivals a process or method which can be detected in the finished product by ordinary or even special means. Many improvements are, however, of such a nature that they cannot be detected in this way, and then the above condition may be found to apply. In most cases this standard is a reasonable one to aim at. More than this can scarcely be expected, unless the patent law comes in to protect ideas and methods for a longer period. When this is realized there is obviously no finality to work of this nature, and as a result a condition of continual change will probably be set up in the factory.

It is surprising to what an extent secret working has in some cases secured a monopoly. Especially is this so when the effect of a process or use of a machine is not self-evident or easily traced in the finished article. Under such conditions, and more particularly where an industry has not adopted a scientific control, a certain sequence of operations has been known to remain the monopoly of a firm, or a limited number of firms, over many years—as witness the turkey red industry.

Even where a close examination of the finished product might suggest, to the experienced investigator, the method of treatment employed, its presence is often overlooked or unsuspected because of difficulties in the way of identification or analysis. A slight and inexpensive change in manufacture may add 10 per cent to the apparent value of a textile material. What this means on a large output can easily be imagined, as the ordinary net profit on manufacture may be somewhere between 20 and 35 per cent.

The research chemist is, therefore, constantly trying to improve or devise methods of investigation which will enable him to keep in touch with the work of those who, for the time being, may be regarded as his competitors; and the methods utilized to this end are based more often upon personal experience than published results. Such processes generally deal with the recognition of certain physical or chemical changes which occur when the material is subjected to tests corresponding to those in actual practice. Owing to their value to the investigator, such methods are not generally disclosed. Work in this direction, or modifications in accepted processes of analysis, and in the proper interpretation of results, are often carefully guarded, until through some change in procedure, they no longer retain their original value. Many such examples will occur to the technical chemist.

The aim of the chemist in this respect is to obtain some clue of a physical or chemical nature which will suggest to the experienced investigator the nature of superior working methods. Such methods of obtaining an insight into hitherto unknown processes or applications are of considerable value. They can only be successfully used by the investigator who has a practical knowledge of manufacture in addition to an ordinary laboratory experience. Thus, to the industrial research chemist, analysis may have a different meaning to what it has to the general consulting chemist. It is a means to an end which possibly may be the discovery of the

* From lectures delivered before the Institute of Chemistry, and published in *Nature*.

[1] It should be remarked that these statements relate to conditions prevailing in England, where the average age at graduation is rather less than in the United States.—Editor.

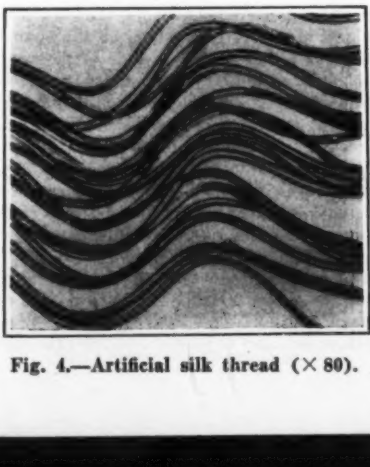


Fig. 4.—Artificial silk thread (× 80).

Fig. 5.—Crêpe de Chine, satisfactory finish (× 30).

Fig. 6.—Same material, unsatisfactory finish (× 30).

nature of a process. Analysis is also utilized to obtain the correct working conditions of a new process, or the better control of an old one. It will be gathered from these remarks that procedure must in many cases be empirical in its nature.

The research chemist often has to watch ordinary manufacturing operations over extended periods before any plan of control or improvement can be devised. Light is sometimes thrown upon such a position by the occurrence of irregular results in the daily output, or a systematic examination of the effects produced by accidental, or predetermined, variations in working conditions. Many problems have been successfully investigated by such means. Such variations, as they occur in everyday practice, may often lead to important improvements, or even suggest new processes. Thus, the research chemist will soon realize that his right place is in the works. He will use the laboratory mainly to follow up ideas in detail.

The introduction of new methods naturally calls for an immediate re-examination of the conditions of working of existing processes. This may often secure to them an extended lease of life, as in the case of the collodion method of preparing artificial silk. In these days of costly apparatus for plant, this factor must not be lost sight of. It is the first point to consider when the chemist finds he has to deal with, and equal, the results obtained, by the introduction of a more efficient process, leading to the production of a better or cheaper product.

The successful worker must, however, go further than this. Experience indicates that important results have generally been obtained by striking out boldly in a new direction. The risk connected with such pioneer work can always be minimized by working on a moderate scale, and making sure of the details of every step as it occurs in a natural sequence. With long experience, it is sometimes possible to experiment at once on a large scale with a reasonable chance of success, but this course should never be followed by the beginner. Such conditions are comparatively rare, and generally governed by some secondary consideration, such as the prohibitive cost of new apparatus, as compared with the utilization of that already available in the works.

In industrial research, it is sometimes more important to know what not to do than the reverse. This restraining influence must be developed equally with originality. In this, the worker will naturally be guided by instinct, which may be defined as the tempering of past experience by an untiring caution.

Once more, the young chemist may be urged to spend most of his time in the works, only working in the laboratory when some work requires systematic investigation. Many manufacturers have objected to this procedure in the past, but with tact, such opposition, where it still exists, can generally be overcome. The industrial chemist who remains in his laboratory will be hopelessly left behind in the race for progress.

It is impossible to say how far the chemist should experiment in the laboratory, or when he must carry out the necessary investigation in the works itself. In the latter case, it is well to leave such labor as does not entail exact measurement in the hands of the workman. The chemist must, however, *know how to carry on such work*, and in cases of difficulty, be able to do so under the eyes of the workman. This is sometimes a rather trying experience to the novice, but it must be faced.

Be careful, when starting experimental works, and reasonably certain that all data which can be obtained on a laboratory scale are already secured. Only then should the establishment of experimental works be attempted. Much can be done in the way of experimental plant, etc., in the laboratory with $500. An experimental works will probably absorb anything between $15,000 and $50,000 before any important results or improvements can be obtained.

It sometimes happens that preliminary operations of a seemingly innocent nature induce material changes which cause endless difficulties in subsequent treatment. These disturbing causes will be entirely overlooked if the chemist does not carry his investigations back to the raw material and examine processes on the broadest lines.

In the process of mercerizing the fiber must be kept under a condition of strain during at least one part of the process; and a long staple cotton (Egyptian) must be used if the treatment is to have its maximum effect. The mere chemical operation of mercerizing was, in itself, ineffective (Figs. 1 and 2).

Thus, it is evident that the modern chemist must be prepared to carry his investigations to the extreme limits of experiment, or satisfactory results will not be obtained. Also that he must extend his work beyond the realm of chemistry proper. A more general knowledge and scheme of working are necessary if the laboratory is not to remain a mere adjunct to the engineering department. The term, "chemical technologist," is one which possibly best describes the qualifications of the industrial investigator, and the knowledge he must possess.

When the student considers such processes, he will realize that the difficulties and nature of modern industrial research are closely concerned with detail. This is always so. Many problems of similar importance undoubtedly still exist in the textile industry, but these will be solved only by the trained investigator who attends to this essential point.

Thus, success is often closely associated with the art of carrying existing processes a stage further. It is with the careful working out of additional detail that it is associated.

In numberless cases, progress is only secured by following up a seemingly unimportant point. This being so, the importance of a training, be it self-inflicted or otherwise, which qualifies a man to deal with such problems is evident. In its absence, progress can only be realized by the more slowly working aid of rule-of-thumb.

The presence of this factor has given the rule-of-thumb man great power in the past, for he has at his command a wonderfully accurate instrument in the trained eye. The chemist with all his apparatus is in some cases no match for him.

The investigator sooner or later realizes the essential value of empirical methods, and if he is wise lets the worker know that he does so. In this way the chemist gains the worker's confidence and the latter more clearly realizes the true aim of research. Once this position is established, the workman will naturally direct attention to any variations in working which may occur, or make suggestions of distinct value. The workman has a great advantage. His mind is continuously concentrated on one operation. Thus it often happens that only by a careful study of deviations from the normal will the research chemist be able to report progress. His aim is to explain and control, the workman's to manipulate.

Facts which are but "curiosities" to the workman, and have remained so for many years in some cases, must be carefully investigated in detail by the chemist. They often represent the starting point for improvement—a first aid to progress, when all other means have failed. Time given to such investigation is never lost, for experience in the ways of processes is a commanding asset to the industrial chemist.

Where operations are conducted on a large scale there is a greater chance of recognizing such conditions. An improvement when applied on a larger scale has also a greater value. It is, therefore better for the young chemist to get into a large works; unless he is compelled to enter a single department, in which case the greater freedom in a small works may be more valuable in spite of restricted output.

Attention may be directed to a list of the probable actions which may be involved during dyeing operations, which I advanced some time ago.

(1) A solution state of the dye within certain limits of aggregation as determined by the laws of solution.

(2) A fiber state corresponding to this state of aggregation and of a permeable nature.

(3) Localization of dyestuff within the fiber area through surface concentration effects.

(4) Localization of salts, acids, etc. (assistants), within the fiber area from the same cause.

(5) The direct entrance of dye aggregates by molecular migration, with subsequent reformation of aggregates within the fiber area.

(6) De-solution, due to surface concentration effects ("salting out"), or secondary attraction, between the fiber substance and the dyes.

(7) Primary or chemical action, which may play some part at this stage, and may even in some cases take the place of, or cause, de-solution phenomena.

(8) De-solution effects in the case of basic dyes, which may lead to alteration in constitution, and the production of basic salts in a state of high molecular aggregation (insoluble) within the fiber area.

In recent years, Perrin has suggested that the action of dyeing is a purely electrical phenomenon, and this suggestion has been followed up in some detail by Gee and Harrison in Great Britain.

It is only in certain cases that the chemist has a voice in the purchase of textile fibers, when certain physical or even chemical factors are recognized as being in question.

The need for such supervision may be seen in the agitation which has been actively carried on by trade associations and others concerning the methods used in South Africa in the dipping of sheep.

For some reason best known to the authorities, a sheep dip is officially recommended which consists of a mixture of slaked lime and caustic soda. The effect of this on the wool itself is sufficiently injurious for the selling price of South African wool to be materially affected, and endless trouble introduced in subsequent manufacturing processes in which such wool is used.

It is said that the breaking strength tests show a loss of 18 per cent in the treated wool. Although wool buyers and English chambers of commerce have protested since 1899 against this treatment, it is still carried on, and the directions, issued in the *Government Journal of the Union of South Africa* so recently as March, 1913, still recommend its use, and give particulars of its preparation.

This example must be the only one which can be discussed on the present occasion. Many of the methods used to determine certain differences in the nature of raw materials which count in the subsequent manufacture, as they have been noted, or even controlled, by chemists, are considered to be of a more or less secret nature.

Although we are not directly concerned with the rebleaching of goods, the use of electrolytic bleaching liquors may be strongly recommended for the laundry trade. As the sodium hypochlorite leaves the electrolyzer, it gives better bleaching with weak solutions than the older bleaching liquor does with strong ones. Two of the best-known types of electrolyzers are those of Kellner, and that sold by Messrs. Mather and Platt. In the modern type, the original salt or brine solution passes in a serpentine course between the platinum or carbon electrodes. The salt employed in the solution is never entirely converted on grounds of economy, and care has to be taken to adjust the cost of current to that of the salt to secure economical results. Under present conditions, the cost of electrical energy must be low, but in view of the many advantages which the use of the sodium salt gives the bleacher, the new process will obviously be put to more extended use.

It is a mistake to imagine that the research chemist's work in the textile industry is chiefly concerned with the adulteration of material and supplying the public with something which is not what it appears to be. His work is mainly constructive, and its influence has been for good. Extraordinary results have been achieved in the last twenty years in the direction of actual improvements in manufacture as well as in the cheapening of production.

The manufacture of artificial fabrics direct from a solution of cellulose is a case in point (see Fig. 3), or that of artificial silk as shown in Fig. 4.

The use made of the microscope is seen in Figs. 5 and 6, where the difference in certain finishing operations is clearly disclosed and explained.

It may be noted that the influence of moisture, in its relation to the many operations of finishing adopted in this industry, is paramount. It is probably the most important influence which the investigator has to consider. The presence of moisture in a fiber gives rise to many conditions, which seem to indicate that it is present in more than one condition. This materially adds to the difficulty in determining its true influence. The fact that all the fibers take up moisture, and that this influences them in different ways, is one of the most perplexing problems met with in this industry. It will probably be many years before this matter is properly understood, or explained scientifically, but when this is achieved, light will undoubtedly be thrown on many phenomena which are so obscure to-day; and which, under present conditions, can only be dealt with empirically.

The relative position of the chemist and engineer in the works has given rise to discussion in the past, and still shows signs of not being altogether understood by those interested.

The opposition to the chemist which is said to exist in some quarters has probably been much over-estimated. In the majority of cases the chemist obtains all the necessary aid he may require from the engineering department. As a matter of fact, the engineer always seems interested in the chemist's work. This is due no doubt to the different method of attack adopted by the latter, which, in itself, fully justifies the presence of the chemist in any works.

Under normal conditions the engineer frankly helps the chemist in his experimental work, and this aid is of real service in many ways. Quite apart from his previous training, the chemist will pick up a fair knowledge on the engineering side in the works, which will be particularly useful in cases where he subsequently acts as manager of a department, or even of the works itself.

The chemist should be just as anxious to make friends with the engineer as with the heads of other departments; and the best way to gain experience and knowledge in this direction is to keep in touch with any new experimental plant which may be in course of erection.

In some cases, work will develop in directions which are not naturally covered by any existing department. If the operations involved are complicated, it may be better for the process to remain under his direct management or control. In this case one or more experimental departments may in time be associated with the laboratory.

It is then necessary to borrow men from the engineering

department and to direct their operations. When this happens the work of the chemist becomes still more general in its nature, and additional experience is gained in the management of men and processes.

Where experimental work is rapidly translated into full-scale operations under normal conditions, the control will pass to one of the works departments. This should be encouraged, for the chemist is then more free to continue research in any other directions which may present themselves. But he must always be ready, and able, to resume temporary control if things go wrong, or where further developments are in progress.

The evidence that a merely chemical training is insufficient is fast accumulating and may be emphasized. The chemist may for weeks be working in directions which are physical or even mechanical in their nature rather than chemical. The important point is that *his method of attack is based on a past training in chemistry,* and that, because of this, it will be different from that adopted by the engineer. In this its value rests. This is the point I have tried to emphasize in these pages. Also that success in almost every case depends upon attention to detail. Thus an inferior mind may sometimes succeed when once a main idea has been grasped. These are the points I would especially bring to the notice of the young chemist who is entering the textile industry on the research side.

Sintered Iron Ores Compared*

Experience With Two Important Processes and Data as to Costs

In a paper, printed in a recent issue of the Proceedings of the Engineers' Society of Western Pennsylvania, B. G. Klugh discusses "Sintering Processes for Iron Bearing Materials." This paper was read at a meeting of the society. It is principally a description of the Dwight & Lloyd process, with data on more recent results. Among other things, Mr. Klugh says:

"The efficiency of this process as a desulphuring agency has, in its recent commercial developments, surpassed tests on smaller lots. Pyrites cinder with sulphur ranging from 2.0 to 6.5 per cent has been treated with a product below 0.10 per cent sulphur without variation. In fact, as a result of satisfactory tests, a company is preparing to operate, selling its product on a guarantee of sulphur below 0.10.

"Several thousand tons of an Eastern magnetite, which contains sulphur varying from 1.5 to 4.0 per cent, and was equally objectionable on account of its silica and lime content varying interchangeably 6 per cent either way, have been sintered. The sulphur was eliminated uniformly below 0.15 per cent. It was below 0.1 when the crushing was below ¼-inch in size. This ore had been used in the past, in its raw state, always with bad results. Its use meant scaffolds, slip, scouring, even when small quantities were used. The operators had about concluded that some element or combination of elements, existed in the ore which made its use in the furnace prohibitive. The variation in the fluxing elements was doubtless the cause of the trouble. This is borne out since the 2,000 tons which were sintered were used in the furnace. The results were so satisfactory, that the mine which was closed several years since, for the above reasons, will be immediately reopened.

"The cost of operating a plant of two units, is herewith given for a typical case. Publicity of exact figures will not be proper courtesy to operating companies, nor would be the name of the operating company attaining them. However, the round figures here given have been attained within 10 per cent:

Producing labor	$0.18
Ignition	.06
Repairs	.06
Power 8.8 kilowatt-hours per ton)	.16
	$0.46

"In the Pittsburgh district, with its cheap natural gas, the ignition cost will be only a fraction of a cent. Where power is made at a blast furnace, or steel plant, and used by the same company, the power cost will be much lower than the above given. The labor above consists of one foreman, one machine operator each turn, one oiler (day turn only), and three laborers day turn and two night turn."

The discussion at the meeting, which was extended, was participated in by several interested engineers and metallurgists. N. V. Hansell, said:

"J. E. Greenawalt, who was experimenting with such sulphide ores, made commercial use of the down-draft principle as early as 1905, and credit is undoubtedly due him for having demonstrated that it is practically and commercially feasible to roast and sinter fine ores by the combustion of sulphur, or other heat-producing substances, supporting the combustion by induced draft. It was Greenawalt, also, who introduced the use of the so-called 'porous bed' on the top of the grates in order to protect them, and incidentally to maintain the particles to be sintered in a quiescent state.

"While thus Greenawalt has to be recognized as a pioneer in connection with down-draft blast roasting, a pioneer who combined with his ingenuity an admirable perseverance in working out the details of his exceedingly simple but efficient intermittent method, it must be admitted that the continuous principle with its many apparent advantages is a Dwight & Lloyd feature.

"A little later in his paper, Mr. Klugh speaks about one Dwight-Lloyd unit having a daily capacity of over 150 tons for several months of operation. This is exceedingly satisfactory and undoubtedly indicates that the mixture being sintered is in good condition physically and chemically. The percentage of fuel in the mixture, or percentage of coke, when treating flue dust, is a factor of paramount importance. Also, the granulation of the ore has to be just right. If the ore is too coarse, the charge will lose its heat, and the sintering action may stop entirely; if the ore is too fine, the resistance against the passage of air through the bed may be so high as to considerably increase the sintering time.

"In talking about the use of a layer of limestone directly on the grates, it is only fair to again repeat that this feature was originated by Greenawalt, and enters as an important claim in the specifications of his early patents. Dwight & Lloyd are using this idea in connection with the continuous process under license from Greenawalt. The honor for making down-draft blast roasting an important step in connection with the use of flue dust and other fine iron bearing materials is due Greenawalt as well as Dwight & Lloyd.

"Greenawalt has now got his method in commercial use on iron bearing materials in six plants in this country and two plants abroad (Italy). In addition, there are two plants under erection in the United States, one in Canada and three in Europe and Asia."

In reply to Mr. Hansell, Mr. Klugh in a written discussion submitted later, said:

"It seems best not to attempt to reply to Mr. Hansell's statement of the claims of the Greenawalt process, not only because a controversy over questions of patent infringements and priorities seems hardly in keeping with the purpose of this paper, but also because many of the matters in dispute are now being adjudicated through interference proceedings in the Patent Office, and undoubtedly will later be tested in the courts. Meantime, it is sufficient to say that according to my understanding, Dwight & Lloyd have never maintained that they were the first to use the "down-draft" for metallurgical purposes, or even in connection with the roasting of ores, but they do claim that they were the first to show how this agency could be used for the specific purpose of successfully and completely sintering a thin layer of fine ore, and do it deliberately and unfailingly, in contradistinction to the haphazard, unintentional and usually unwished-for production of irregular masses of sinter with no definite or regular structure which had previously characterized efforts along this line. Besides the questions at issue concerning the down-draft, etc., there are others involved which are quite as pertinent."

Dr. K. F. Stahl, Pittsburgh, said:

"Practically all the processes in which the material is subject to a high heat are being tried. Nodulizing furnaces make a desirable material for a blast furnace at a cost of about $1 to $1.25 per ton. Iron contents depend on the grade of pyrites used, usually about 60 per cent iron. Phosphorus contents compare favorably with the best low phosphorus Lake Superior ore, i. e., 0.01 to 0.02 per cent; sulphur is usually brought down to 0.1 per cent. Powdered coal (10 to 12 per cent) is mostly used for fuel. Mr. Klugh stated that the cost of sintering in a Dwight & Lloyd furnace was less than 50 cents, exclusive of royalty, which would make it the cheapest process known at present."

Regarding the question of the effect of weathering, Mr. Klugh reported:

"The only instance we have of the weathering of Dwight & Lloyd sinter is that of a case at Birdsboro, where, due to the furnace being out of blast, several thousand tons were stocked for a period of about eight months. This period covered March, 1912, to January, 1913, hence included freezing and other weathering conditions. The structure was practically unchanged. There was no disintegration whatever."

The chairman, John S. Unger, manager Central Research Laboratory, Carnegie Steel Company, Duquesne, Pa., asked what provision was made for the variation in a pile of stock flue dust which has been made up of shipments from a number of furnaces, the carbon varying from 5 to 30 per cent in the same pile. Mr. Klugh replied to this by saying:

"The easiest method of handling the variable stockpile flue dust is by concentration. The next easier solution for the sintering operation is by dilution of the carbon with the fine ores which will, under usual conditions, make flue dust. On the other hand, the flexibility of the process allows the use of the raw flue dust as such."

* Reproduced from *The Iron Age*.

Minnesota has a forested area of 28,000,000 acres, which is the largest of any State east of the Rocky Mountains.

Erosion of Canal Bottoms by Boat Propellers

A few years ago Prof. Oswald Flamm of the Charlottenburg Technical High School, demonstrated by the aid of photographs that the revolution of a ship's propeller imparted a spiral motion to the water, and he suggested that the propeller drew the water in from all sides by a kind of suction effect and discharged it again in an axial spiral current. Further experiments in this connection have led him to the view that the axial spiral current to the rear is mainly responsible for the erosion of canal bottoms, which has generally been ascribed to some propeller action, though its nature is not well understood so far. This erosion may become a serious source of trouble, for two reasons. When the canal bottom is washed out, water may leak out of the canal; this is particularly objectionable in raised canal beds, because the escaping water has to be replenished. In the second instance the threatened erosion of the canal banks and bottom obliges the authorities to limit the speed at which boats may be propelled on canals, and thus impede shipping; the opponents of canal construction and improvements have not failed to bring up this argument.

Prof. Flamm's experiments now deserve attention, not only because they seem to indicate the real cause of the erosion, but also because they show that the erosion may be avoided by a very simple alteration of the rudder. Speaking at the Berlin branch of the Verein Deutscher Ingenieure in December last, Prof. Flamm, with the help of the kinematograph, demonstrated that when a propeller was kept stationary, and turned at 2,500 revolutions per minute, the bottom of the canal—consisting of loose sand and clay at a depth of about 3 meters (10 feet)—was little disturbed by the motion, as long as there was no rudder behind the propeller. When the rudder was put in its place, however, being held in the longitudinal axis of the boat, a strong erosion was observed, a hole about 12 meters long and wide and up to 1.6 meters in depth being produced in the course of two hours. This erosion, Prof. Flamm pointed out, was due to the fact that the spiral current from the propeller struck the rudder and was deflected downward by the vertical plane. Dr. Geber, of the Versuchsanstalt für Wasserbau und Schiffsbau, had tried to suppress the erosion by providing two rudders, placing one to the right and the other to the left of the keel-line. The expedient had been successful to a certain degree, but only as long as the rudders were kept in the fore and aft line. When the double helm was put to port or starboard, the erosion became worse than it had originally been; that trouble again could be mitigated by fixing the two rudders far apart from one another so that they always remained outside the spiral current. Such a double helm was expensive and very cumbersome, however.

Prof. Flamm therefore tried another remedy. He fixed to the lower edge of a rudder of the usual type and dimensions a horizontal bottom-plate, a little longer than the rudder itself, as a rule apparently projecting at the rear, and of a width greater than the height of the rudder. This horizontal plate stopped the current which the rudder itself had deflected downward; whether it turned the current toward the side was not mentioned; perhaps the current is broken up and dissipated. When such a plate was used, at any rate, there was no erosion of the bottom to speak of after two hours, and since the experiments were later, on behalf of the government, continued on the Oder-Spree Canal, any noteworthy erosion of the banks would hardly have escaped attention. The horizontal plate prevented erosion at all positions of the rudder, while with the ordinary rudder without the plate erosion was always noticed. In alluding to these experiments during the discussions of the November meeting of the Schiffbautechnische Gesellschaft, Prof. Flamm mentioned that he had, so far, experimented with ten different tugs on the canal, and he had almost always been successful; the dimensions of the plate had to be adapted to the conditions, and the expense for providing the rudder with a suitable plate had been about $25. The plate, moreover, seemed to increase the axial thrust, by as much as 10 per cent in some cases, probably because the plate served as a guide-vane. It was further noteworthy that steering was decidedly facilitated by adding the plate. If these observations should generally be confirmed, the addition of the horizontal plate to the rudder may become an important innovation.—*Engineering.*

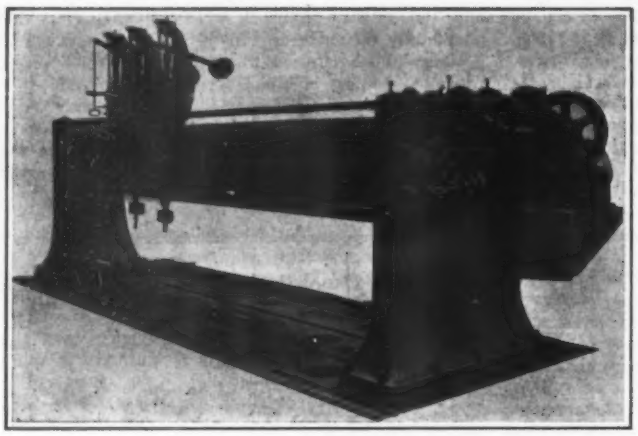


Fig. 1.—Electric tube-hole drilling-machine.

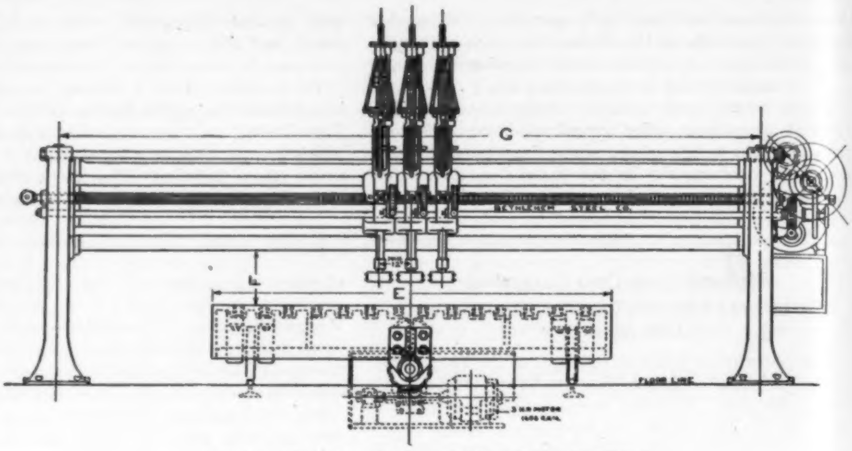


Fig. 2.—Elevation of the machine shown in Fig. 1.

The Development of Electrically Operated Tools

Plate-bending Rolls and Hole-cutting Machines Designed at South Bethlehem

By Frank C. Perkins

Our front page illustration shows powerful electrically driven plate-bending rolls at the plant of the Bethlehem Steel Company. The view also shows the direct current electric motor used for operating these rolls, the gear being located at the bottom.

Many improved electrically driven tools for use at this plant were designed to save time and labor not only in rolling the plates, but also in drilling and cutting holes, both round and oval, in boiler shells; and in trimming the product to proper sizes and shapes.

The accompanying illustration, Fig. 3, and drawing, Fig. 4, shows another equipment of electric power-driven plate-bending rolls developed at South Bethlehem. This machine has three forged steel rolls, arranged in pyramid form, which run in bearings having brass bushings supported in massive housings, which rest on a heavy cast iron bed plate extending under the entire machine.

It will be seen that the two lower and lighter rolls which are supported from the base by rollers to prevent deflection are driven in either direction through extra heavy gearing shrouded for the lower reductions. The top or friction roll is made much heavier and has its bearings arranged in such a manner that the roll may readily be tilted by means of a hand wheel and screw. This permits the easy removal of plates when bent to a complete circle, and, in addition, this roll has vertical adjustment permitting plates to be bent to radial or conical shapes. These machines are designed for electric motor drive and are provided with either hand or power adjustment for the rolls.

Among the other electrically driven tools, designed at this plant, may be mentioned the electric boiler-shell drilling-machine seen in Fig. 5. The great amount of time and labor ordinarily expended in setting a portable machine for each rivet hole to be drilled in a boiler shell has necessitated a more economical method of performing this operation.

The machine illustrated occupies a floor space 46 feet 2½ inches in diameter and is built with a stationary center table, having a radius of 5 feet 5 inches, surrounded by a circular track, upon which are mounted one, two, three or four independently operated carriages, each of which is propelled by a 5 horse-power motor.

Resting upon suitable ways on each carriage is a vertical stand which receives a 7-foot radial adjustment from a screw with which the carriage is provided, having a hand operated ratchet attached. Secured on top of each stand is a 5 horse-power motor geared to a screw to give the 13-foot vertical adjustment to the drilling head which is counterweighted on the inside of the stand.

The drilling heads are each provided with a 7½ horse-power variable speed motor which drives and feeds the four spindles. In addition to the variable speed motor, the spindles are back geared and the feed gears are ranged to give four different feeds per revolution of the spindle. Each spindle is adjusted independently by hand so that one, two, three or four holes may be drilled at one setting inside a 16-inch diameter circle.

The minimum distance between hole centers is 5 inches, allowing by staggering of the drilling a minimum spacing of 3⅜ inches. The drilling head has a 12-inch horizontal movement to the vertical center line of the stand which provides for the spindle feeds. The heads are built to drill at once four 1½-inch diameter holes in boiler shells ranging from 9 to 21 feet in diameter, and by reversing the shell, over 24 feet long. The uppermost hole may be drilled 13 feet 6 inches above the table.

In order to avoid the waste of time and labor consumed in drilling holes and resetting the boiler plate for each row of tube holes to be cut, as is necessitated by the methods commonly employed, a short time ago an electric-driven tube hole cutting machine was designed by the engineer of Bethlehem Steel Company, as indicated in photograph, Fig. 1, and drawing, Fig. 2. Since the motion of the table and of the cutting heads are at right angles any portion of the plate may be brought under a cutter, which is arranged to give the required size hole without any preliminary drilling.

This machine is constructed for cutting one or more holes at a time, according to the number of heads with which it is provided. The plate in which the holes are to be cut is bolted to a movable table fitted with wheels running on a track. This table is of cast iron, 10 feet wide by 16 feet long, and has its top provided with "T" slots. On its under side are the bearings and wheels and a screw operated by a 3 horse-power motor to give the 14 foot 3-inch longitudinal travel which may also be obtained by hand.

On either side of this table are the housings carrying a heavy cross rail upon which slide the cutting heads. The housings are 17 feet between centers and the right hand one carries the brackets for the motor and drive gears. The housings and cross rail are all box-shaped iron castings of heavy design. The cutting heads slide on the cross rail and obtain their motion by either hand or machine power in such a manner that it is possible to move each independently or all together.

In each head is a spindle provided with a 9-inch vertical feed, which can be controlled collectively at the right housing and individually at each head. These feeds are arranged in three steps 0.002, 0.004 and 0.008 inch per revolution of spindle. Each spindle head is arranged for No. 6 Morse taper, which, together with a complete equipment of drill press attachments, permits each cutting head to perform all the functions of a drill press. In addition, each spindle has a special attachment for keeping the cutter properly centered while cutting a tube hole.

The maximum size tube hole that can be cut is 4 inches in diameter, and the greatest distance from center to center of outside spindles is 15 feet 6 inches, while the minimum distance between spindles is 12 inches. The machine is driven by a 10 horse-power variable speed motor, 450 to 900 revolutions per minute, which, with three pairs of change gears, give a spindle speed ranging from 15 revolutions to 120 per minute with the steps in a geometrical progression.

The entire machine is supported on a structural steel

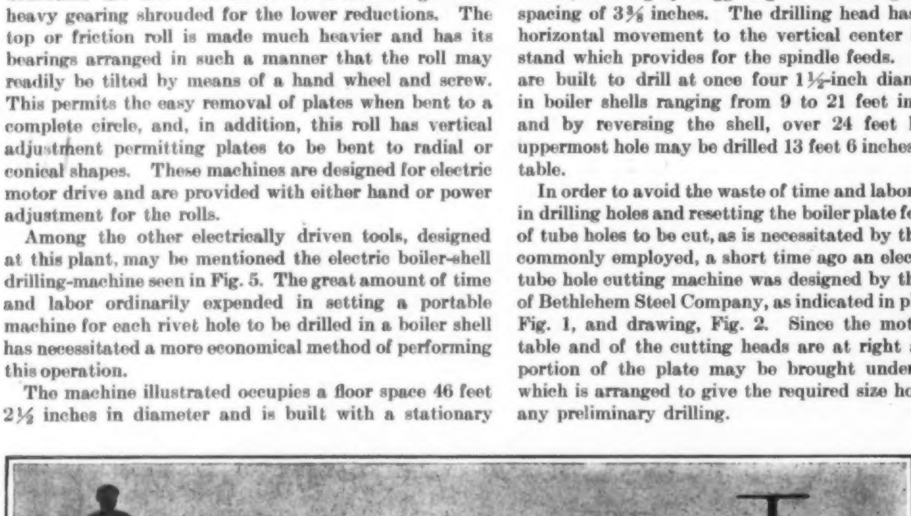


Fig. 3.—Electric power-driven plate-bending rolls, horizontal type.

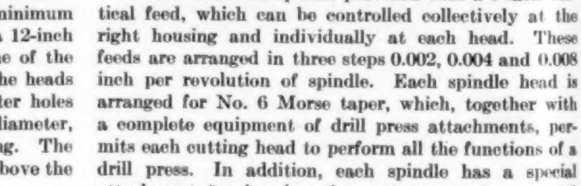


Fig. 4.—Elevation of the machine shown in Fig. 3.

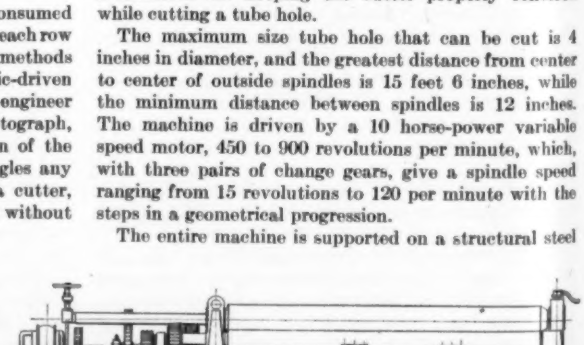


Fig. 5.—Electrically operated boiler shell drilling-machine.

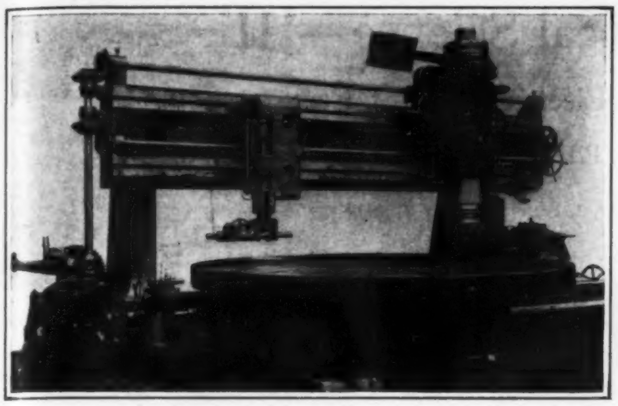


Fig. 6.—Round and oval hole cutting machine, electrically driven and controlled.

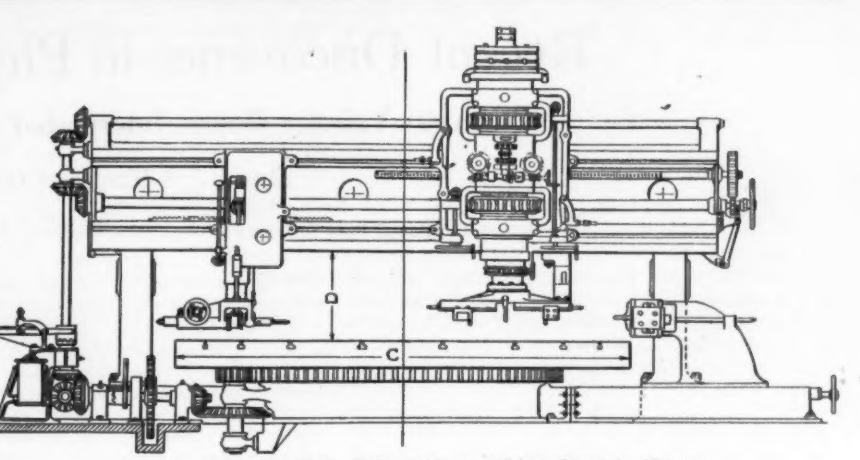


Fig. 7.—Elevation of the hole cutting machine shown in Fig. 6.

foundation to which are bolted the housing tracks and foundation plate for the table-moving mechanism. The gears and parts subject to severe service are forged of fluid-compressed open-hearth steel and the iron castings have a tensile strength of at least 18,000 pounds.

In boiler-shop machinery, as in all other classes, that type which combines stability and a large range of output economically produced is cheapest and most satisfactory. The electric driven hole cutting machine seen in photograph, Fig. 6, and drawing, Fig. 7, has a table made to accommodate a boiler head 16 feet in diameter, with flanges 12 inches high. At a single setting of a head its flanges can be turned up, holes drilled in it, also one or more round or oval holes cut with the major axis in any desired direction.

These holes range in eccentricity from zero to 6 inches, the largest being 48 inches in diameter if circular, or 48 inches for major axis if oval. These operations are all rapidly accomplished by simple adjustments of the machine. Until this machine was designed several years ago all other machines required a resetting of the boiler head for each hole, aside from being unable to perform the additional operations of turning the flange and drilling holes in it. The base of this machine consists of three box-shaped iron castings rigidly bolted together, with an extension base for the motor and change gears. The central part of the base has a large flat way to receive the table where is also located the conical adjustment bearing for the table spindle.

The right hand part of the base is machined for one housing, to the bottom of which is bolted the flat extension base for the motor and change gears. The table is cast iron, 14 feet 6 inches in diameter, and has its top side faced and provided with a large number of radial "T" slots. On its lower side is a large circular bearing running in the flat way on the base. This flat way is arranged to be filled with oil. On the under side of the table is a conical spindle for the adjustment bearing, and, securely bolted fast, is the cupola gun iron main driving gear.

This gear is made up of six segments and has a pitch diameter of 10 feet, circular pitch of 2 inches and a 6-inch face. The driving pinion is made of cast steel. The table speeds range in a geometrical progression from ¼ revolution to 4 per minute by means of two pairs of change gears and a variable speed motor having a ratio of one to two. The table may be set by hand through releasing a clutch which then automatically grips the machine drive in the setting gear. There is a locking arrangement provided to rigidly hold the table when the main cutting head is in operation. The tool post for turning the flanges is located to the right of the table and its tool head is provided with hand feed only. The housings and cross rail are cast iron, box-shaped and made very heavy. The hole cutting head is arranged to slide on the right side of the cross rail, to which it is rigidly clamped when set to cut a hole. The frame for the head is made of cupola gun iron and the spindles of fluid-compressed open-hearth steel. The spindles are three in number, viz.: the inside, outside and setting. The first two are power driven, the third is not, its only function being to regulate the eccentricity.

This is accomplished by turning the setting spindle relatively to the outer spindle until the desired eccentricity, within the range of the machine, is indicated by the graduation. The eccentric motion of the cutting tool is obtained by having the setting spindle placed eccentrically in the outer spindle and the inside spindle put an equal amount off center in the setting spindle.

Once the machine is set the setting and outside spindles revolve as one, while the inside one turns at exactly the same speed in the opposite direction. This causes the tool which is fastened to the inside spindle to cut a positive ellipse which becomes a circle when the spindles are so set that the two eccentrics exactly counteract each other. The spindles are driven by heavy worms and worm wheel; the innermost, having a diameter of 10 inches, carries the tool post head upon which slide the two tool posts.

These are set by hand for the size hole required and clamped. When cutting oval holes but one of the cutting tools is to be used. The hole cutting head may be moved along the cross rail by hand or power and is provided with clutches throwing out the machine drive and setting arrangement to permit the direction of the major axis for an oval hole to be obtained. The spindles are counterbalanced and provided with both hand and automatic feed, which latter has three steps, viz.: 0.004, 0.008 and 0.016 inch per revolution of spindle, or a total vertical feed of 10 inches.

The minimum spindle speed is ½ revolution and the maximum 8 per minute, derived from the same motor and pairs of change gears that are used for the table. The drill head is arranged to slide on the left side of the cross rail and is clamped to it while drilling. This head is designed for a maximum hole of 1-inch diameter and is capable of a 10-inch vertical adjustment and horizontal drill feed of 12 inches operated by hand or power. The machine is driven by a 20 horse-power variable speed motor of 550 to 1,100 revolutions per minute operating through driving gears, all of which are made of steel with cut teeth, except the main gear segments for the table and worm gears for spindles, which are all made of cupola gun iron.

The cast iron of this machine has a tensile strength of not less than 18,000 pounds; all cupola gun iron not less than 25,000 pounds, and all steel is of standard superior quality. The electric trimming shears are of special interest. These cold plate trimming shears must be of the greatest strength and rigidity. The stroke given the head by means of the usual eccentric shaft is timed by a clutch, which is operated by a foot lever with counterweight release. This motor driven machine is built to cut plates 72 inches wide by 1 inch thick or less and occupies approximately 130 square feet of floor space. It stands about 11 feet high and weighs approximately 10,000 pounds, with a stroke of 1½ inches and a gap of 6 feet 6 inches, the depth of throat being 9 feet 20 inches. The knife is 3 feet from the floor and 4 feet 6 inches from the bottom of the machine.

Notes on Invisible Light

By Dr. W. R. Whitney

The object of these notes is to cover very briefly some of the points of interest in modern electrical theory, particularly with reference to such radiations as are given by X-ray tubes or radioactive material. It may help to review the conceptions of atoms, electrons and ether waves, for the subject is intimately connected with the constitution of matter and of electricity. Formerly the chemical atom was considered the ultimate indivisible particle. While this still has a significance for positively charged matter, another single and much smaller mass has been discovered in the electron. This consists of a negative electrical charge which is always the same in magnitude and to which a mass is attributed of about one eighteen-hundredth that of the hydrogen atom. This magnitude, the sign of the charge, its velocity, etc., have been determined from measurements of the effects of electrostatic and magnetic fields upon it. It is to the motion of these negative charges or electrons through metals that we attribute the flow of current. More is known about their flow across various spaces and within gases than elsewhere. They move with velocities varying with the potential gradient through which they fall. In such places as so-called "hard" X-ray tubes the velocity of the electrons is already known to exceed half that of light. The electrons are capable of passing through thin aluminium foil and even when this is earthed they emerge with their original charges. Material is in general, however, opaque to these electrons.

There seem to be no positive electrons corresponding exactly to the negative ones. The smallest positively charged masses yet known are the atoms of elements from which the negative electrons have escaped. These heavy positively charged particles of matter are well known and they act about as one would expect. They move in electrostatic fields with a velocity much lower and in the opposite direction to the negative. Ponderable matter of the atoms accompany them or constitute them. They do not pass through ordinary matter and are easily filtered out of gases.

Thus we see a differentiation of great importance which we express by saying that electricity exists in ultimate units which are negative charges. Their inertia, i. e., the property which by definition determines mass, makes them out to be much smaller than any other particles of which we know.

When these moving negative electrons are stopped by contact with material, then X-rays are set up. It is believed that these ether waves are set up by the impact of the electrons on the atoms of matter. These are exceedingly short waves in the ether, otherwise very like light waves. They possess greater penetrability, however, but also affect photographic plates.

These three things, positively charged atoms, negative electrons, and ether waves, are common to radium also; so while no attempt is being made here to cover entirely the properties of either, or the similarity or differences between radium and an X-ray tube, the following rough statements may be of help.

There are three kinds of emissions from radium, viz., alpha, beta and gamma rays. The positively charged atoms of matter from radium are the alpha rays. In the vacuum tube these correspond to the so-called canal rays and were discovered by studying the rays which passed through holes in the cathodes into the space behind the cathode. This is what we would expect if there were any such positively charged particles in a discharge tube.

The negative electrons of radium constitute beta rays and have been well studied. They correspond to the electrons which are shot off from the cathode in an X-ray tube. By their impact upon the anti-cathode or target, the X-rays are produced. Similarly the impact of the beta rays of radium are apparently the cause of the gamma rays of radium, as it is known that the impact of beta rays on solids produces gamma rays. These correspond to the X-rays. Both the gamma rays and the X-rays are ether vibrations of high penetrating power. Their velocity is in each case that of light. It is true that the penetrating power of the gamma rays is greater than that of the ordinary X-rays; but X-rays are of widely different penetrating power, though of the same velocity. The penetrative power should now be under control as it depends on the voltage across the X-ray tube. The hardness of an X-ray tube corresponds to the electromotive force necessary to produce and maintain the current of negative electrons through it, so that if this is made greater the hardness is raised. The greater the hardness the more penetrating are the X-rays produced. Evidently then the application of higher voltages to suitable X-ray tubes should give continually increasing penetrating power of the rays.—*General Electric Review.*

To Prevent Cooling Water Freezing.—During the past winter the soldiers in charge of the motor wagons in the Prussian army were instructed to add 40 per cent of glycerine or alcohol to the cooling water in order to prevent it freezing. Where benzole is used, instructions were issued to add to it 25 per cent of gasoline or at least 15 per cent of tolu oil.

Recent Discoveries in Physical Science—III*

Chemical Valency Bonds Interpreted as Electric Lines of Force

By Sir J. J. Thomson, O.M., F.R.S.

Continued from Scientific American Supplement No. 2000, Page 275, May 2, 1914

There are many compounds, of which ordinary copper sulphate is an example, in which the molecule is a combination of two systems, each of which is capable of existing by itself in the free state. The molecule of copper sulphate in its ordinary condition can be represented as

$$CuSO_4 + 5\,H_2O.$$

Of this combination, the system $CuSO_4$ can exist by itself, and the H_2O is, of course, also stable when alone. Each, in fact, constitutes in itself a saturated compound with the valencies of all the atoms satisfied. The existence of the molecule $CuSO_4 + 5\,H_2O$ shows, however, that, even so, the two systems still possess the power of forming compounds by the action of what are sometimes known as residual affinities, or, as Werner calls them, "auxiliary valencies." These auxiliary valencies can bind together one molecule to another, thus forming additional compounds. The auxiliary valencies differ from the ordinary valencies in that the ordinary valencies bind one atom to another, or to a radical, while the auxiliary valencies are only able to bind together molecules, and cannot bind atoms. Compounds formed by the exercise of these auxiliary valencies are therefore sometimes known as molecular compounds. Whatever the origin of this power, it cannot be expected to bind an ordinary atom, since it cannot "saturate" that atom, and the result will be that the unsaturated valencies of the latter will combine with another atom on the first opportunity.

Compounds bound together by auxiliary valencies have quite definite properties. The molecule $CuSO_4 + 5\,HO_2$ has, in fact, properties quite different from the molecule $CuSO_4$ and from the molecule H_2O. Such molecular compounds are in most cases very fairly stable. Thus ordinary copper sulphate has to be heated to 100 deg. Cent. before it loses any of its combined water, and up to 200 deg. Cent. before the water can be entirely driven off. When $CuSO_4$ is in combination with water it has, as stated, entirely different properties from what it possesses when free from water. One of the properties most frequently altered is the color. The attraction of water to the dry molecule produces in certain cases remarkable changes of color. Thus, anhydrous cobalt chloride is blue, while when the molecule combines with water the color is pink.

It is difficult to draw a line between molecular compounds and the ordinary chemical compounds in which the constituents of the molecule are held together by the ordinary chemical valencies. A remarkable feature is, however, that in every case of a molecular compound one, at least, of the molecules concerned has its atoms charged with electricity. Water is a typical example of such a compound, but alcohol and ammonia are other instances of compounds having charged molecules, and capable therefore of forming molecular compounds. Molecules having charged atoms are able to exert a much stronger external field than can molecules in which the component atoms are neutral, and in which when entering into the combination there is merely a displacement of the electricity on the surface of the atom, and not a transference of a charge from one atom to another.

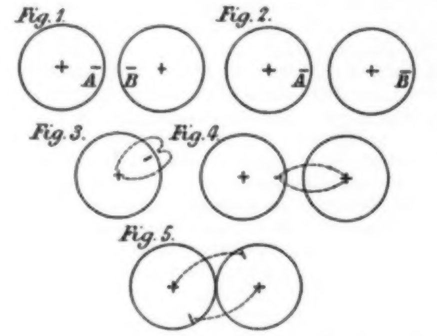
The external force exerted by the water molecule, in which the hydrogen is positively charged and the oxygen negatively, is accordingly much greater than that which is exerted by marsh gas (CH_4), in which neither the hydrogen atoms nor the carbon atom carry charges.

The laws governing molecular combinations have been studied by many chemists, and especially by Werner. They are found to be somewhat analogous to those which hold in the case of the ordinary valencies. As to the latter the carbon atom, for example, cannot hold more than four atoms of hydrogen, four of chlorine or an equivalent number of other atoms. There is a similar limit to the number of molecules which can be held in molecular compounds. This is what might be expected from very general considerations indeed. For instance, the molecule of HCl has charged atoms, and can therefore attract like a magnet. If placed in water, a molecule of water will be attracted to the hydrogen, say, and being the first to arrive, will attach itself in the position with the strongest field. When a second molecule comes up and also attaches itself to the hydrogen atom, it will push the other about a little, so that neither occupies quite the best position in which the attraction is strongest. Neither, therefore, will be held quite so strongly as the first molecule was initially. When a third molecule of water comes up and also hangs on to the hydrogen atom, the bond will be still weaker. With every addition the hold gets weaker and weaker till it becomes insufficiently good to withstand the collisions from other molecules to which the system is continuously being subjected. It is natural, therefore, to expect a limit to the number of molecules that can be held by the auxiliary valencies. There is a similar attraction of water molecules to the chlorine atom of the HCl, so that ultimately there is a bundle of water molecules hanging on to each atom of the hydrochloric acid molecule, and hence the final resultant compound molecule may be quite large. The size is limited only by the number of molecules which can attach themselves in this way to an atom. Werner reached the conclusion that the maximum number in any one bundle did not exceed six.

The avidity with which water molecules, in suitable conditions, rush to attach themselves to other molecules can be easily illustrated.

[Taking a glass vessel with a little water at the bottom, and filled with SO_2 above, the lecturer showed that, on passing a powerful beam of light through it, a cloud was formed, owing to the condensation of the moisture on the molecules of SO_2. He also showed an experiment due to Prof. Townsend, in which electrolytic oxygen was allowed to bubble up into a vessel traversed by a powerful beam of light, and showed again that a cloud was formed by the condensation of moisture on the gas.]

One point about these molecular compounds is that



the addition of other molecules may facilitate the charging up of the atoms in the original molecule, so that greater changes may be produced than would be due to the sum of the properties of the two individual molecules. This can be exemplified by the case of sal ammoniac, formed by the action of ammonia on hydrochloric acid. Both NH_3 and HCl are compounds in which the constituent atoms are charged. When such compounds form molecular combinations there is a tendency for the ammonia to drag the hydrogen away from the chlorine in the hydrochloric acid, and dissociation of the latter may occur accordingly, the result being a mixture of the various constituents in a condition of statical equilibrium.

Another difference between the compounds with charged and those with uncharged atoms may prove to be of some importance from the chemical standpoint. The physical properties of water and of marsh gas are very different indeed, and it is of interest to see whether there is any corresponding difference in the laws by which such different classes of compounds are formed. In other words, are the effective valencies the same in compounds with charged atoms (ionic compounds) as in cases in which the atoms carry no charges. I hope to give reasons for showing that there is a very distinct difference in the two cases. Certain compounds are possible under the valency law when the atoms are not charged which are not possible when the atoms carry charges. The latter, the ionic compounds, obey the ordinary valency laws of the chemist. If however, the atoms are uncharged, we can get, in addition to the ordinary compounds, others formed in accordance with an extension of the usual valency law.

In discussing this matter it is necessary to form some physical conception of what valency really corresponds to. I take it that each atom contains certain negative corpuscles. Of these some are firmly fixed at the core of the atom, and take no part in any chemical reaction. There are, however, other corpuscles on the surface free to move about and set themselves into position under external electric fields. It is these mobile corpuscles which enable one atom to hold on to another, and form the material of the bond between the two. The valency is equal to the number of these mobile corpuscles, so that in a univalent element there is one such mobile corpuscle, in divalent elements there are two, in trivalent three, and so on up to seven mobile corpuscles. With eight corpuscles in the outer ring, however, we get a rigid system, in which the corpuscles cannot move relatively to one another.

The mobility of these negative corpuscles is the essential condition for one atom to exert any considerable attraction on another. Suppose, then, we had an atom with one free corpuscle, as represented diagrammatically in Fig. 1, with its negative corpuscle at *A*. If another such atom were brought near it, with its negative corpuscle at *B*, repulsion would ensue; but the corpuscles, being free to move, would be driven round to the other side as indicated in Fig. 2, and the positive charge of this second atom being now the nearer to the negative corpuscle at *A*, attraction would ensue, the initial repulsion being momentary only. In such a case the final result would therefore always be an attraction whatever were the initial conditions.

If, however, the corpuscle in the atom were fixed, it could not be swung round without carrying with it the whole of its atom. This atom is quite a heavy body, difficult to move, while the negative corpuscle has almost no inertia, and can, therefore, if free, be driven round at once.

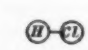
Hence when the negative corpuscles are mobile the atoms hold each other together, but when fixed they attract each other to a very much less extent. An atom is saturated when it has all its negative particles fixed, the satisfaction of a valency being essentially the fixing of one of the mobile negative particles.

[The difference in the attraction exercised by mobile and by fixed doublets the lecturer illustrated by means of a series of small magnets. It was shown that when these were resting at random on a suspended tray, there was very little resultant attraction when a powerful electro-magnet near by was excited, while the attraction was large when the magnets were mounted on pivots, and were thus free to move round and set themselves.]

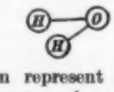
Each negative particle in an atom is the origin of a tube of force. If the atom is alone, the tube of force returns into the atom and ends on the positive charge, as indicated diagrammatically in Fig. 3. In such a condition the negative corpuscle remains quite free to move. If, however, the tube of force terminates on some charge external to the atom, the corpuscle will be fixed. This condition is represented in Fig. 4, and the particle is then deprived of its mobility and is unable to attract another atom.

Suppose next that the second atom is neutral, then there will be a similar tube of force from it to the first atom, as indicated in Fig. 5. In fact, with uncharged atoms, for each line of force which leaves an atom there must be a return line, as many coming in as go out. If the atoms are divalent, then two lines of force will leave each and two return, so that the total number of tubes of force between the two is in such cases always double the number of valency corpuscles.

Suppose, however, that a corpuscle passed from one atom to the other, so that one atom became positively and the other negatively charged. As the corpuscle left it would follow its tube of force, which would thus shrink up into the interior of the second atom, and the condition of affairs would then be that represented in Fig. 4, but with only one tube of force between the atoms. In compounds with charged atoms, therefore, the number of lines of force between the constituent atoms is only equal to the chemical valency, while it is double the valency when the atoms are uncharged. The tube of force is, in short, the chemist's bond, which he represents by a bar, thus:



With divalent atoms the chemist writes, for example:



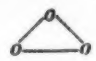
and the bars again represent simply lines of force. The chemist, however, makes no distinction in the number of lines, whether the atoms of the compound carry charges or not, taking the number in both cases to be equal to the valency.

This, however, is only true if the atoms are charged, the number of lines of force being doubled when the

* Third of a series of lectures delivered at the Royal Institution.

atoms of the compound are neutral, and the theory here proposed differs in this respect from the chemical view. It might be thought that this would make no difference, but, as a matter of fact, in the scheme suggested, certain combinations become possible, which are impossible on the old chemical theory. Take, for instance, H_3. Hydrogen is univalent, and, according to the chemist's view, we could not have such a combination as

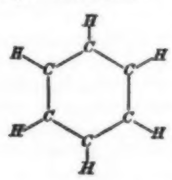
since in this diagram two lines of force are represented as issuing from each hydrogen atom. On the other hand, ozone is quite possible from the chemical standpoint, oxygen being divalent. Ozone can be represented as:



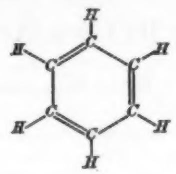
On the view I have now brought forward the compound H_3 is, however, quite possible if its constituent atoms are uncharged, since in that case there would be two lines of force to each hydrogen atom, one line of force coming in and one going out.

It will be seen, therefore, that on this view many compounds are possible which are incompatible with the ordinary theory. Benzene, for example, is a famous instance of the difficulty of reconciling the ordinary views as to the valency with the constitution of the molecule.

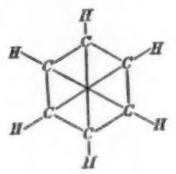
It is ordinarily represented thus:



Here each carbon atom is represented with three valencies only, and the difficulty is to dispose of the fourth. Kekulé suggested that the fourth valencies were arranged as indicated below:

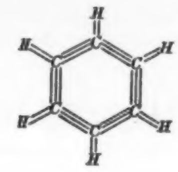


There are then, it will be seen, four lines from each carbon atom. This, however, leads to difficulties, since it will be seen that the molecule thus constituted is not perfectly symmetrical, and the more chemists have worked at benzene the more convinced they have become of its perfect symmetry. Armstrong has accordingly suggested the constitution:



Here the fourth affinity is put into a kind of reserve fund at the center of the molecule, and is not ordinarily utilized. This device restores the symmetry of the benzene ring, though it gives no very clear idea as to what becomes of the fourth affinity.

On the hypothesis I have put forward the difficulty disappears. Benzene is a molecule with its atoms uncharged. Hence there are eight and not four lines of force associated with each carbon atom, and two and not one line of force associated with each of the hydrogen atoms. The constitution can, therefore, be represented as shown in the following illustration:



This arrangement satisfies all the valency conditions, and leaves the ring perfectly symmetrical. It does not conflict with the ordinary chemical view, but extends this by the hypothesis that when we are dealing with compounds having uncharged atoms the lines of force between the constituents are doubled.

In times past I have been inclined to think that chemists were disposed to make excessive use of structural formulæ in which the forces binding the molecule together were represented by lines. I must confess, however, that I am now greatly impressed with the utility of this device, even when used by the chemists I had suspect of pushing it to extremes. From a physical standpoint I now believe that these bonds really represent something with a physical basis at the bottom, though formerly I had been inclined to believe that such formulæ were often artistic rather than scientific. I am, however, now convinced that the chemist's bonds do really represent actual lines of force.

On the new view certain compounds would be capable of existing which are as yet unknown. This objection, however, applies equally to the older view. The valency laws, in fact, merely show the possibility of certain compounds, but give no data as to their stability. The architecture of compounds, constituted according to these laws, might therefore be correct, but the resultant edifice might be unstable as to structure. For example, molecules can exist with unsaturated affinities, because the effect of the molecular collisions may suffice to keep them from combining, even though they have a certain tendency so to do. This can be illustrated with N_2O_4, which splits up into NO_2 as the temperature is raised, as is shown by the change in the color of the gas.

(To be concluded.)

Experimental Evidence of Molecular Structure

At a recent meeting of the Physical Society, Prof. R. W. Wood delivered a lecture* on "The Molecular Vibrations Excited by Light-Waves," and pointed out that he had studied them because he had wished to try and find out the mechanism of molecular structure. The most important conclusion at which he had arrived from his researches was that what was ordinarily called absorption by vapors and gases was not really absorption at all, but a scattering or diffraction of the light in all directions by the molecules. In this lecture, he proposed to deal with the illumination or fluorescence of vapors and gases resulting from their illumination by ultra-violet light. At the ordinary room temperature, mercury gave off an exceedingly attenuated vapor, which, when illuminated by the ultra-violet light from the mercury arc, emitted ultra-violet light of the same wave-length as that of the illuminating beam. He described how, working on this principle, he had constructed a new type of lamp, which he called a resonance lamp, by means of which several curious effects could be produced. The peculiarity of the light emitted was its extreme purity. It was much more nearly homogeneous than the light constituting the spectrum lines of the metallic arc. The mercury resonance lamp consisted of a bulb of fused quartz, highly exhausted, and containing a small drop of mercury. The mercury vapor in the bulb was then at a pressure of 1/760,000 of that of the atmosphere, and became strongly luminous when the light from a mercury arc-lamp was focussed upon it. The light emitted was invisible to the naked eye, and could only be detected by photography. In fact, what had been done in the experiments was to focus invisible light on invisible vapor, and to photograph the invisible light that came off the invisible vapor. So nearly was the light homogeneous that it was possible to photograph by it the vapor arising from a drop of mercury placed in a cylinder, and heated to 5 degrees above the room temperature, appearing in the picture as a black smoke. A small flask of transparent quartz containing a drop of mercury when illuminated by light from this lamp appeared as if filled with ink. This resulted from the facts that the light from the resonance lamp was exactly synchronous with the natural vibrations of the mercury molecules, and that they responded in the same way that a tuning-fork responded to a sound equal in pitch with its own.

Photographs of the resonance lamp showed that if the silica bulb was gradually heated, the luminosity, instead of being uniformly distributed throughout the cone of the exciting light, retreated to the front wall of the bulb until it was eventually confined to a thin layer of vapor. The reason was that at higher densities, the waves of light were stopped, and then re-emitted in all directions by the mercury molecules before the light had penetrated to a depth of more than a small fraction of a millimeter. Sodium vapor might be used instead of mercury. A glass bulb was highly exhausted, and pure metallic sodium placed in it. When the temperature in the flask reached about 200 deg. Cent., the image of a sodium flame thrown on it became visible on the vapor in sharp outline, just as if it had been received on white paper. Experiment had shown that if the sodium light was pure enough, the refractive or diffractive power of the vapor was nearly as great as that of white paper, though as colorless and transparent as air when viewed by ordinary daylight. What could only be detected photographically, in the case of mercury, could be seen by the naked eye in the case of sodium. The increase in the density of the vapor in the flask might be compared roughly with the optical behavior of milky water and milk. A beam of light would pass through milky water, but would be stopped by milk. As was well known, the vapor of sodium gave yellow light

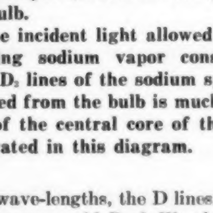


Fig. 1.—When the silica bulb is heated, the luminosity, instead of being uniformly distributed through the cone of exciting light, becomes confined to a thin layer (shown in black) at the surface of the bulb.

Fig. 2.—If the incident light allowed to fall on a bulb containing sodium vapor consists of the broad D_1 and D_2 lines of the sodium spectrum, the light re-emitted from the bulb is much purer, consisting only of the central core of the D_1 and D_2 lines, as indicated in this diagram.

of two different wave-lengths, the D lines. In collaboration with M. Dunoyer, said Prof. Wood, he had shown that in illuminating sodium vapor by the light of one of these yellow lines only, it was possible to get sodium vapor emitting only one D line, a fact that proved that the atomic mechanism that gave rise to these lines was not connected. This result was contradictory to the experiments undertaken with other vapors, in which the excitation of one line by monochromatic light caused the re-emission, not only of the same wave-length, but of a large number of other wave-lengths, bright lines appearing at regular intervals.

STIMULATION BY LIGHT-WAVES.

Experiments were also described, in which such gases as oxygen and nitrogen had been caused to emit ultra-violet light as the result of stimulation by light-waves that were probably shorter than any previously known. These waves were given out by the electric spark between metallic terminals, but proceeded only a short distance in air, being very rapidly absorbed. The shortest wave-lengths previously known had been described by Schumann. They were completely absorbed by quartz, but passed readily through a considerable thickness of fluorite. While these new waves would pass through a fluorite plate one millimeter thick, they were reduced in intensity to about 2 per cent of their original value. The light emitted by the gases, owing to the shortness of the wave-length, was in most cases invisible, though iodine vapor emitted a green light, if mixed with nitrogen and subjected to the rays, remaining dark, however, if mixed with oxygen. Ordinary air, when stimulated by these waves, gave out a light which the spectroscope showed to be identical with the ultra-violet light emitted by the oxy-hydrogen flame. The advantage of studying the spectra by these methods was that in many cases they could be much simplified, and the relation between the lines brought out. The best illustration of this was the fact already described that it was possible by this method of working to cause sodium vapor to emit one only of the two characteristic yellow lines of the sodium flame.

The study of the structure of the molecule by means of the spectroscope, the lecturer said, might be likened to the attempt on the part of an individual who had no experience with or conception of any musical instrument to get a clear idea of all the musical instruments of an orchestra by listening to a concert, or an attempt to form an idea of a piano by listening to the sound which it gave out when falling downstairs. Methods of exciting radiation such as the spark, the arc, and the flame excited all the lines simultaneously, the acoustic analogy of which was to sound the piano by sitting on the keyboard. Optical methods of exciting radiation corresponded to the striking of a single note at a time on the piano. The most important result of his investigations on these lines had been the establishment of the fact that what was ordinarily called absorption by vapors and gases was not absorption at all, but a scattering or diffraction of the light in all directions by the molecules. On looking at a light through the vapor black absorption lines were seen, because the vapor had diverted the light from the original beam, and thrown it in all directions. It was then possible to pass by gradual stages from this molecular scattering to true absorption, where light was transformed into other forms of energy, either by increasing the density of the vapor itself, or by mixing it with some chemically-inert gas, the absorption appearing to be brought about in some way as a result of molecular collisions.

*Reported in the *English Mechanic and World of Science*.

Electro-Cardiography*

How the Heart Is Made to Register Its Own Action By the Electricity It Generates

By Hans Guenther

THAT day, at the commencement of the eighteenth century, in which Galvani first saw a frog's leg contract under the influence of electric force, was the birthday of electrotherapy as well as of electrotechnology.

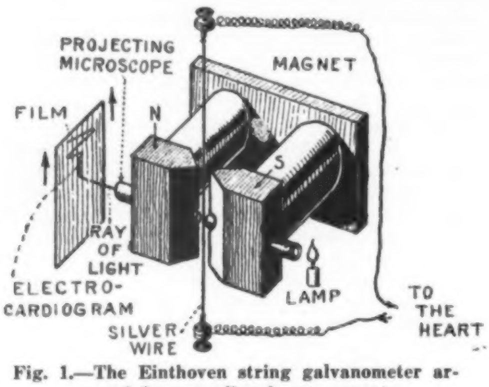


Fig. 1.—The Einthoven string galvanometer arranged for recording heart currents.

Galvani's discovery not only inspired the researches of Volta, which resulted in the construction of the voltaic pile, the first-known source of electric current; it also led to a lively controversy concerning the forces in action in the frog's leg, in the course of which Galvani laid the foundation of our knowledge of the generation of electricity in living organisms. The superstructure was raised by Du Bois-Reymond and many later investigators, and now we know that every contracting muscle, every filament conducting a nervous impulse, every secreting gland, every illuminated eye, every active vegetable cell is capable of producing an electric current, often of astounding strength. This biochemical current is caused by the chemical transformations which are continually taking place in every active living cell.

This universal fact possessed only theoretical interest until a few years ago, when it was made the basis of a new method of studying diseases of the heart, which has since been developed to a high degree of technical excellence.

Electro-cardiography may be defined briefly as a method of recording the movements of the heart by means of the electric currents which are produced by the contractions of the heart muscle. These contractions do not occur simultaneously in all parts of the muscular mass. The base of the heart, which contains the two auricles, contracts first; after a short pause the apex of the heart and the corresponding part of the two ventricles contract; finally, after another pause shorter than the first one, the middle part of the ventricles contracts. Next, the whole heart remains motionless for an instant, and then the contraction begins again in the auricles. Hence a contracted part of the muscle is always in contact with an uncontracted part. Now, as every contracted muscle is the seat of an electric tension, which does not exist in an uncontracted muscle, the contracted and the uncontracted parts of the beating heart exhibit differences of electric tension which produce an electric current, if the two parts are connected by a conductor. The manner in which this difference of tension is destroyed in the organism does not interest us at present as deeply as the question whether it is possible to include the heart in a circuit containing an instrument by which the heart currents can be measured.

This possibility is given by the fact that the bodily tissues are conductors, through which the heart currents can be led into an external circuit. As the heart lies to the left of the median plane of the body, and its axis is oblique to that plane (Fig. 2), the currents are not distributed uniformly through the body, but go chiefly to the arms and legs. It is as if the limbs were wires attached to the heart, so that we need only connect the right and left extremities through a galvanometer in order to measure the heart currents.

After this rough sketch of the physiological facts on which electro-cardiography is based, we pass to the technical part of the problem. The well-known instruments which measure the strength of an electric current by its deflection of a magnetic needle, by its chemical or thermal effects, etc., are too coarse for the measurement of the very feeble and short-lived currents produced by the heart's action. For these and other bio-electrical measurements it was ncessary to invent special instruments, of which the most perfect, until very recently, was the Einthoven string galvanometer, the principle of which is illustrated in Fig. 1. A fine wire of silver or platinum is stretched like a violin string between the poles of a powerful electromagnet. When the wire is traversed by an electric current its middle part is displaced from its position of equilibrium to an extent proportional to the strength of the current. The wire is illuminated from one side, and on the other side is placed a microscope, which projects an image of its shadow on a moving photographic film. As the movements of the wire and its image correspond with the fluctuations of the current, and these with the movements of the heart, an accurate record of the heart's action is presented by the electro-cardiogram which appears on the developed film.

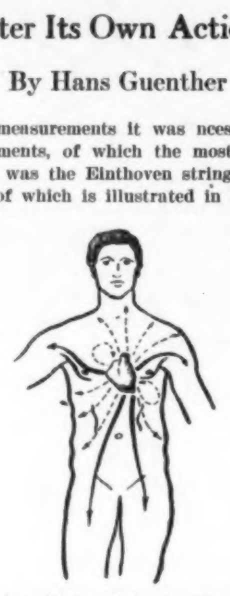


Fig. 2.—The position of the heart and the distribution of the heart currents.

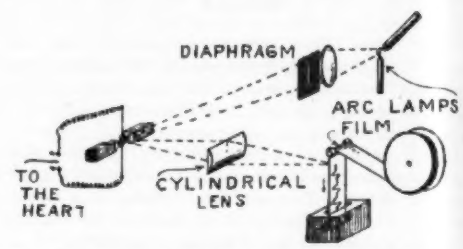


Fig. 3.—Diagram of Siemens and Halske electro-cardiograph.

Hitherto, almost all electro-cardiograms have been made with the Einthoven galvanometer. This excellent instrument, however, possesses some defects, or rather inconveniences, which impair its usefulness to overworked practising physicians. The optical apparatus is not easy to manage and the regulation of the tension of the wire, which greatly affects the result, presents many difficulties. These inconveniences led Siemens and Halske to substitute for the stretched wire a light wire coil, carrying a little mirror and suspended between two exceedingly fine wires.

Fig. 3 is a diagram, and Fig. 4 shows a photograph of the complete electro-cardiograph based on this construction. The galvanometer proper—a refinement of the mirror galvanometer which has long been employed in physical laboratories—is illustrated in Fig. 5. The little coil, suspended between the poles of the magnet and traversed by the feeble heart current, turns about its axis of suspension through an angle so small that it can be measured only by a ray of light which, reflected by the mirror attached to the coil, moves over a distant screen, like a long pointer.

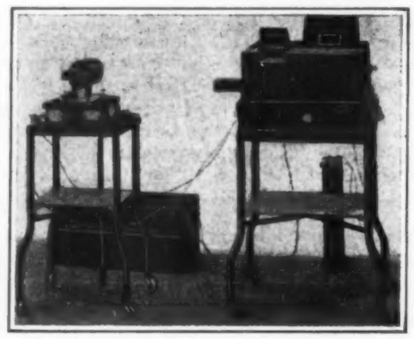


Fig. 4.—Siemens and Halske electro-cardiograph.

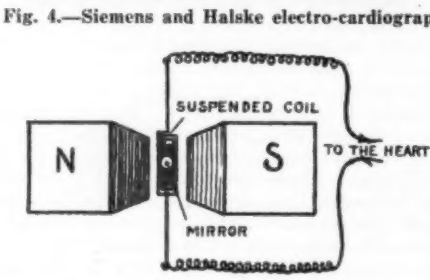


Fig. 5.—Mirror galvanometer of electro-cardiograph.

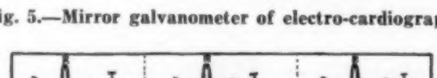


Fig. 6.—Normal form of electro-cardiogram.

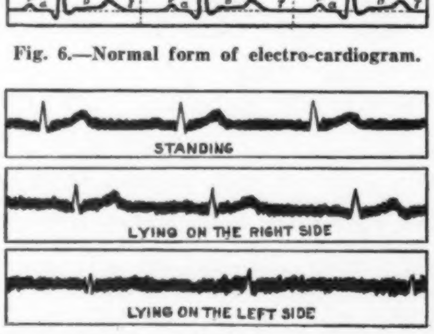


Fig. 7.—The effect of posture on the cardiogram.

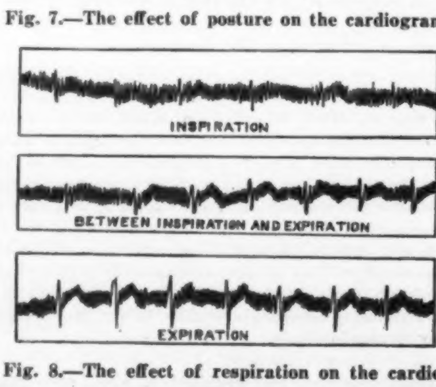


Fig. 8.—The effect of respiration on the cardiogram.

After this explanation the operation of the apparatus can easily be comprehended with the aid of the general diagram (Fig. 3). The rays of an arc lamp, converged by a condensing lens, fall on a slitted diaphragm which allows only a narrow beam of rays to reach the galvanometer mirror. The beam reflected from the mirror passes through a cylindrical lens, and is thus converged to a small and intensely bright spot of light, which records its movements on a moving band of photographic film. The developed film shows the electro-cardiogram as a sharply defined black trace on a white ground (Fig. 6).

The apparatus can be connected with the heart in various ways, for example, by placing the hands and feet in four glass vessels filled with water, to which electrical conductivity has been given by the addition of salt. The length of the wires that connect the water with the galvanometer does not affect the result, so that the patient and the apparatus may be in different rooms, or even in different buildings. This, indeed, was proved by Einthoven, who made in his laboratory in Leyden electro-cardiograms of patients in a hospital more than a mile away. By this method of telecardiography, therefore, a diagnosis can be made at a distance.

This brings us to the question of the practical value of electro-cardiography. What can the physician learn from the undulating curve that the patient's heart traces on the film? This curve (Fig. 7) consists of undulations arranged in regularly recurring groups, each of which represents a complete contraction, or systole, of the heart. In each group we find three elevations, *P R T*, differing in height, and three approximately level stretches, $\alpha\,\beta\,\gamma$. The elevations represent stronger or weaker impulsive currents, and consequently more or less powerful muscular contractions, while the level stretches correspond to intervals of rest. The significance of the undulations becomes evident when we recall the rhythm of the heart's contractions. The first elevation *P* corresponds to the contraction of the auricles.

* Translated for the SCIENTIFIC AMERICAN SUPPLEMENT from *Technische Monatshefte*.

the stretch a to the ensuing pause, the second and highest elevation R to the contraction of the apical part of the ventricles, the stretch β to the second pause, the elevation T to the contraction of the middle part of the ventricles, and the stretch γ to the comparatively long interval in which the whole heart remains at rest until the next beat begins with the contraction of the auricles.

This cardiogram represents the normal heart action of a healthy man. Disease of the heart or any disease that affects the heart, violent exertion, even a change in the manner of breathing, produces changes in the heart's movements, which are accurately recorded in the electro-cardiogram. In these facts reside the great value of the new method of diagnosis, which has been developed especially by Nicolai and Kraus. The condition of the heart is shown by the form of the curve. If the elevations P and T are very low, the heart is weak; if the point R is lower than the general level marked by the stretches, $a\ \beta\ \gamma$, the heart is affected by neurosis; if the point T is directed downward the patient suffers from arteriosclerosis. In the transition from an erect to a reclining posture the curve changes in the manner shown in Fig. 7. Respiration causes the changes illustrated in Fig. 8.

In the electro-cardiogram, therefore, the heart writes its own story, and that of the whole body, so that electro-cardiography is an almost unparalleled method of physiological exploration. Physiology and electrotechnics have an equal share in the development of this new method of research, which presents a striking illustration of the high state of electromedical science.

A School of Porpoises at the New York Aquarium*

The Difficulties Encountered in Bringing the Catch from Cape Hatteras to New York Alive

By C. H. Townsend

After several discouraging attempts with animals more or less injured, the Aquarium has, not merely a single healthy porpoise, but a school of them. They were received without injuries of any kind, and have already lived in the building much longer than any single injured specimen hitherto received. After five and a half months in a pool 37 feet in diameter and 7 feet deep, they continue to be in apparently the best of condition, feeding, leaping and otherwise disporting themselves after the manner of porpoises on the high seas.

No more popular exhibition of marine life has ever been made in the Aquarium. To have these lively rangers of the open ocean dwelling in our midst is fascinating, and every citizen who has failed to pay them a visit should do so at once, for, although present prospects are good, there is no certainty about the future with wild animals in captivity.

Two previous attempts were made to bring porpoises from Cape Hatteras. Although arrangements for their shipment were perfected, the instructions given were not carried out by those to whom the shipments were entrusted. In the first instance all the animals died before they could reach New York, as they were unfortunately shipped dry and could not survive the journey without the cooling and supporting medium of water. The next attempt, made last June, when the same blunder was made, gave only slightly better results. Four of the six porpoises shipped died between Hatteras and Norfolk, Va. At the latter point the shipment was met by the Director of the Aquarium, who promptly filled the tank containing the two survivors with water. One of the animals died soon after reaching New York, but the other lived two and a half months, notwithstanding the fact that the heating it had undergone during the first stage of shipment produced numerous festering sores, which eventually ended its career.

Firmly believing that plenty of cool water would insure safety during transportation, the Director of the Aquarium went to Hatteras November 7th, to make sure of the details of shipment which, entrusted to others, had been neglected. As far as the adult animals are concerned, the results have been satisfactory. There are five adults about 8 feet long still living, but the four half-grown porpoises died soon after their arrival in New York. The adults gave no trouble during shipment, while the young were exceedingly restless and continually bruised themselves by their struggles in the shipping tanks.

Porpoises are warm blooded, blubber-covered mammals and give off so much heat that the water of the shipping tanks becomes actually warm, requiring to be replaced by cold water every five or six hours. Immediately after their capture at Hatteras, where they were dragged on the beach with a seine about a thousand feet long, the porpoises were placed for 24 hours in a salt water pond just back of the ocean beach. No chances whatever were taken in the matter of temperature. On the beach their natural heating would no doubt have been accelerated by the hot sunshine. The following day they were seined out of the pond and placed in the shipping tanks, which were then hoisted on board a schooner and filled with water. During the voyage up Pamlico Sound and even through the Great Dismal Swamp Canal the fresh water in the tanks was changed whenever it became warm. After reaching the New York steamer at Norfolk the cooling of the porpoise tanks *en route* was greatly simplified by the use of the salt water hose.

Dragging a porpoise from the net.

The shipping of porpoises alive is, therefore, a simple matter. Adult animals readily stand transportation, while the young animals do not. If carried in long, narrow boxes, just sufficiently large to accommodate them without rubbing, and if kept supplied with sufficient cold water to support and cover them, they can be handled easily enough. There is probably no reason why a porpoise, under such conditions, should not be carried in a tank many times the distance from Hatteras to New York.

Recapturing the porpoises in the salt-water pond.

Our porpoises are rather expensive boarders, consuming between 80 and 90 pounds of fresh herring or tomcod a day. For a few days after their arrival they would eat nothing. Within a week they began to take a few live fishes, and, after having once started to feed, it was not difficult to get them to take dead fish. A few days of hunger brought them around, as it does in the case of the newly captured seal or sea lion.

Cape Hatteras, singularly enough, is the only point in North America where a porpoise fishery has ever been regularly conducted. The bottle-nosed porpoise appears to winter off our South Atlantic coast and is quite common in the vicinity of Cape Hatteras during the Fall, Winter and Spring months. Schools of porpoises may be seen passing every day just outside the surf. They are taken with a net about one thousand feet long, which is placed a couple of hundred yards outside the line of surf and parallel with it. At each end there is a boat in waiting, ready to carry the haul lines directly ashore as soon as a band of porpoises has passed between the net and the surf. After the lines have been carried ashore, the porpoises are considered fairly secure, for they do not often attempt to cross the lines, and, even when they do, can usually be frightened back by having someone shake and jerk each line continuously. It requires some time to bring the ends of the big seine to the beach, but even then some of the porpoises may get away by leaping over the net or attempting to dive under it. The former can be prevented to some extent by sending a boat to the outer curve of the net, which serves to keep the porpoises from crowding against it. Some of those that attempt to dive underneath become enmeshed, and, being air breathers, are soon drowned.

Thirty-three porpoises were beached in the haul of the seine which provided our specimens. Although porpoises have been taken at Cape Hatteras from time immemorial, the fishery has been conducted in a merely desultory manner, with but little capital invested. The greatest number taken in a single year appears to have been about 1,000. Porpoises are valuable for their jaw oil, body blubber and hides, the value of each being in the order given. The oil derived from the jaws represents the greater part of the value, being worth ordinarily \$25 a gallon. This oil is extracted from the broad posterior branches of the lower jaw. It is practically the only oil used for the lubrication of watches and similarly delicate mechanisms.

The bottle-nosed porpoise (*Tursiops tursio*) is the only species of porpoise that has ever been taken at the Hatteras fishery. Our 8-foot specimens represent the average size. A number of specimens were measured in November, however, which exceeded 9 feet in length. The greatest length for this species at Cape Hatteras is 12 feet, but this is altogether unusual. The specimens were presented on the beach at Hatteras by Mr. Joseph K. Nye of New Bedford, Mass., the proprietor of the fishery. They were transferred to New York at the expense of the New York Zoological Society.

The porpoise exhibit in the New York Aquarium is absolutely unique. No other aquarium in America or Europe is fitted with pools large enough to accommodate porpoises, and it is doubtful if there are at the present time any other specimens in captivity.

Our bottle-nosed porpoise (*Tursiops tursio*) closely resembles *Delphinus delphis*, a species of porpoise or dolphin more abundant in the Eastern Atlantic and in the Mediterranean than along our coast. The latter is

* By permission of the New York Zoological Society.

Launching the boat: The porpoises are coming.

A haul of the porpoise seine, Cape Hatteras, November 12th, 1913.

the dolphin known to the ancients, which, for some unknown reason, has been systematically caricatured by painters and sculptors since the very beginning of art. Sculptors now have an opportunity to visit the Aquarium and see what the real dolphin looks like.

In the matter of name there is some latitude. All porpoises and dolphins belong to that family of the order of whales called *Delphinidæ*, or dolphins, of which there are at least fifty different species, and the names porpoise and dolphin are to some extent interchangeable.

The former is, however, usually applied to the short-jawed kinds. The name "bottle-nose" is inapt in the case of such animals, as the nose or nostrils of all dolphins and porpoises is on top of the head.

The name dolphin is also applied to a fish (*Coryphæna*).

The Problem of Three Bodies*

A Classic Problem Solved: Its Application to Celestial Bodies Under Mutual Gravitational Attraction

By F. R. Moulton[1]

One of the most celebrated problems of mathematics is that of determining the motion of three bodies which attract one another according to the Newtonian law of gravitation. Nearly all of the great mathematicans from Newton to the present time have bestowed upon it their profoundest meditations. Its literature contains memoirs by Euler, Lagrange, Laplace, Poisson, Gauss, Jacobi, Cauchy, Delaunay, Adams, Weierstrass, Poincaré and Darwin, to mention only a few of those who have attempted to penetrate the recondite regions which it includes. These names call to mind many of the finest achievements in mathematics, and the fact that they are all attached to investigations in the same domain proves at once its importance and its difficulty.

The problem of three bodies is of great importance because it is a first step toward the problem of the motions of the members of the solar system under their mutual attractions. The sun, earth, and moon offer an example on which enormous labor has been bestowed, the sun, Jupiter, and Saturn present an example which must be treated by different methods; and triple stars having comparable masses constitute still another case. There are reasons which are obvious to one interested in astronomy why we should be able to predict the positions of the members of the solar system. But the question of its stability, how the orbits of its members have changed in the past, and what alterations they will undergo in the future is from certain points of view much more important. The solution of the problem of three bodies is a prerequisite for a complete and final discussion of the origin of the solar system, its past evolution, and its prospects for the future—questions which have always been of profoundest interest to thinking men.

It is easy to see in a general way the source of some of the difficulty in the problem of three bodies. In order to make the matter perfectly concrete consider the sun, Jupiter, and Saturn, neglecting all the other members of the solar system. As was first proved by the founder of celestial mechanics, Sir Isaac Newton, Jupiter would describe an exact ellipse about the sun as a focus if it were not for Saturn (and the other disturbing bodies); and similarly, Saturn would describe an ellipse about the sun as a focus if it were not for Jupiter. The disturbing attraction of Saturn pulls Jupiter somewhat from its elliptical orbit, and similarly Jupiter pulls Saturn from its orbit. These disturbing forces vary in a complicated fashion because the planets move around the sun at different distances, at different rates and in different planes. The effects of the disturbing forces vary in a still more complicated fashion because they depend not only upon the magnitudes of the forces themselves but also upon the parts of the orbits which the disturbed bodies occupy. In spite of the complexity of this problem it can be solved for such a system as the sun, Jupiter, and Saturn. But the fact that Saturn has been pulled from its undisturbed elliptical orbit makes its disturbing effects upon Jupiter different from what they would otherwise have been. The deviations of Jupiter which have been considered, result in corresponding secondary effects upon its own motion. Similarly, there are secondary effects upon the motion of Saturn due to the fact that both it and Jupiter have departed from their elliptical orbits by the primary perturbations. These secondary effects on the orbits of both bodies give rise to tertiary perturbations upon each. The tertiary effects give rise to those of the fourth order, and so on in an unending series. The deviations increase very rapidly in complexity with their order, and the fact that they soon become numerically less important in such problems as present themselves in the solar system, is the circumstance that has made them tractable by the methods that have so far been employed.

The questions that at once arise are whether the problem of three bodies is soluble and whether it has been solved. The purpose of this paper is to answer these questions, so far as they can be answered at the present time, without the use of elaborate mathematical discussions. In a certain sense the answer to both of them is in the affirmative. The answer to the second of these questions is in the affirmative in quite a new sense because of a recent remarkable work by Karl F. Sundman of Helsingfors, Finland. In a certain theoretical sense his results far surpass any heretofore secured. His whole discussion is of the very highest order of excellence; in fact it is so highly regarded by competent European judges that the distinguished and venerable editor of *Acta Mathematica*, Prof. Mittag-Leffler, invited him to republish the memoir[2] in detail in his journal whose pages already were enriched by the researches of Poincaré, Darwin, and Weierstrass. This is another example of the excellent mathematical work which so frequently comes from Finland. Every student of differential equations and the profounder parts of celestial mechanics has long been familiar with the name of Lindelöff. It shakes one's belief in the justice of the pride in race when he remembers that the Finns are not even of Aryan stock,[3] and of European peoples are related only to the Hungarians. In numbers they are only five or six millions; they are poor and live in a relatively desolate and inhospitable country; they were subject long to Sweden and now to Russia. In spite of all these conditions, ordinarily considered to be the exact opposite of those which are necessary to give lesiure for pursuing the higher things of life, the work which comes from Helsingfors compares most favorably with that produced by many wealthier and more populous peoples.

The present condition of the problem of three bodies will be best understood by giving something of its history. Before taking up the account of its development it should be stated, in order to prevent all misconceptions, that while it is in a certain sense solved, it is by no means finished. In fact, it has only been begun.

A necessary prerequisite to the treatment of the problem of three bodies was the discovery of the laws of motion and the law of gravitation. These laws were based on an enormous amount of observational experience, from prehistorical antiquity to the culmination in Kepler's laws of the planetary motions. It was from the observations of the motions of the heavenly bodies that men first perceived that there is order in the Universe. This perception lies at the very basis of science, and without it science would not exist. When it was discovered that apparently the heavenly bodies are moving in an orderly fashion, the next problem was to find the laws of their motions. Among those whose names stand out particularly in connection with the solution of this problem are Hipparchus, Ptolemy, Tycho Brahe, and Kepler. The genius of Newton derived from these laws the law of gravitation.

In order to treat the problem of three bodies it was necessary also to have powerful mathematical processes. The development of mathematics has been parallel with that of astronomy; in fact, the latter in very many cases has forced problems in the former and has often pointed to their solution. But back of particular mathematical theories there lie the logical processes by which they are elaborated. These rules of logic are probably an epitome of the relations among the experiences of the race. At any rate, the logical processes are not contradictory to the Universe about us. In the times of the ancient Greeks all the principal rules of logic were definitely formulated. Certain branches of mathematics were extensively cultivated, but the methods of analysis, which alone are sufficient for making progress in the problem of three bodies, were initiated by Newton and Leibnitz in their invention of the calculus. The calculus is but the introduction to the analysis which has grown up in the last two centuries. Those branches of analysis which are particularly valuable in such problems as that of three bodies are especially what is known as the theory of functions of a complex variable and the theory of analytic differential equations based on the theory of functions. Everyone is familiar with the power of the methods of the calculus as compared with those of the more elementary parts of mathematics. The methods of the theory of functions are similarly more powerful than those of the ordinary calculus. It is only by their use that such results as those of Poincaré and Sundman have been secured. The chief difficulty in this paper is to present these highly technical matters in popular terms.

The treatment of the problem of three bodies was begun by Newton in the "Principia." On the basis of his law of gravitation he discussed by synthetic, or geometric, methods the deviations of the moon from elliptic motion which are produced by the disturbing action of the sun. He explained qualitatively all the principal perturbations, and secured quantitative results of considerable approximation. He conceived of the moon as moving in an ellipse whose size, shape, and position continually change. This conception, which grows very naturally out of the ideas connected with the problem of two bodies, has been central in a large part of the perturbation theory. There are grounds for believing that in some respects it has been unfortunate, especially in treating the motion of the moon.

The successors of Newton were Clairaut, d'Alembert, and Euler. They developed analysis corresponding to Newton's geometry. Their methods had the generality which is characteristic of analysis, and they were much superior to those of Newton in getting numerical results. But most of their work was devoted to a discussion of the motion of the moon. The methods which they employed were those of successive approximation. The processes were not proved to converge, and therefore no particular properties of the motion of the moon were rigorously established. They were guided, however, by keen physical and geometrical intuitions, and direct observations of the motions of the moon proved that their theories were capable of representing the perturbations with considerable approximation, if not exactly. But theories of this sort, whatever practical value they may have, are not the ones of primary interest in this paper. The center of interest here is on those things which were absolutely proved, with only a secondary interest in their numerical application. In the line of exact results secured by these men mention may be made of the ten integrals of the motion of the problem of three (or any number of) bodies. The problem of three bodies is of the eighteenth order; that is, eighteen integrals are sufficient to solve it completely. Or an equivalent statement is that the complete solution involves eighteen arbitrary constants. Of these eighteen integrals, ten were found by the immediate successors of Newton. Six give the theorem that the center of gravity of the system moves in a straight line with uniform speed; three, that the sums of the products of the masses and the projections on the three reference planes of the rates the respective radii describe areas are constants, and the tenth, that the total energy of the system, both kinetic and potential, is constant. No additional integrals are known for the general case.

The chief immediate successors of Clairaut, d'Alembert, and Euler were Lagrange and Laplace. They perfected the theories of their predecessors and developed corresponding theories for the mutual perturbations of the planets. On the whole their work was marked with greater generality than that which had preceded. One of the most interesting conclusions of a general character, to which both Lagrange and Laplace contributed, was that the major axes of the planetary orbits have no secular terms; that is, they do not on the average increase or decrease. This result was proved only for perturbations of the first order, and even then by breaking up the differential equations in a manner which was not logically justified. Hence, while the conclusion undoubtedly represents the facts closely for a very long time, it was not completely established. The process was not proved to converge and there was no discussion as to what the higher order terms might indicate. The subject was carried somewhat further by Poisson, who proved that so far as the terms of the second order are concerned the conclusions are in a general way the same. Eginitis has found important differences in the terms of the third order, and Poincaré has proved the process does not converge, so that any conclusions which are drawn from it may be erroneous.

So far in the discussion no rigorous solutions of the problem of three bodies have been mentioned and no rigorous results, except those which follow from the ten integrals, have been cited. However, in 1772 Lagrange found certain exact solutions of the problem of three bodies. The memoir of Lagrange on this subject has been greatly admired because of the elegance of its form, and the solutions which he proved to exist are very well known. The solutions are characterized by the fact that

* Reproduced from *Popular Astronomy*.

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[2] The work was originally published in *Acta Societatis Scientiarum Fennicae*, vols. 34 and 35. It appeared in *Acta Mathematica*, vol. 36 (1913).

[3] It should be stated that the writer is not positively informed as to the race of Lindelöff, Sundman, and other Finnish scientists.

the bodies move so that the ratios of their mutual distances are constants. Their orbits are plane curves and conic sections with the center of mass as a focus. They move so that the law of areas is true with respect to the center of mass as an origin. That is, their motion is qualitatively exactly like that in the problem of two bodies. Whatever the relative masses of the three bodies may be, they can be projected from the vertices of any equilateral triangle in such a way that they will always form an equilateral triangle. If the orbits are circles or ellipses the triangle will always be of finite size; otherwise its dimensions become indefinitely great as the time increases indefinitely. Another solution is that in which the three bodies are always in a straight line which, of course, changes its position in space. In this solution the relative distances of the three bodies from one another depend upon their relative masses.

No solutions of the problem of three bodies in which the character of the motion was known for an arbitrary interval of time were discovered for more than one hundred years after the memoir of Lagrange. The next solutions having this property were those given by Dr. G. W. Hill in 1878 in his celebrated researches on the lunar theory. He defined certain periodic orbits related to the orbit of the moon, and computed the coefficients of the expressions for the coördinates with a very high degree of precision. In the strictest sense Hill did not solve the problem because he neglected a small part of the disturbing action of the sun, viz., the part known as the "parallactic terms." But his method was extensible almost without change so as to include these terms, and the details were carried out by Brown in the earliest of his papers on the lunar theory. This work of Hill, together with his epoch-making memoir on the motion of the lunar perigee, laid the foundation for an entirely new lunar theory which has been completed by Brown at an enormous cost of labor in a splendid series of papers. It is intended here to emphasize the point that starting from a particular *exact* solution of the problem of three bodies as a first approximation a new method of treating the motion of the moon has been developed. It was the first absolute abandonment of the idea, originally due to Newton, of regarding the orbit of the moon as a varying ellipse. The radical departure from standard lines of procedure shows Hill's originality, and the extraordinary skill with which he developed his ideas proves that his mathematical ability is of the first order. While the exact solution discovered by Hill has been of very great value in one of the most important problems in celestial mechanics, the solutions of Lagrange have found almost no applications and have had very little influence on astronomy. The only exceptions to this statement are that a suggested explanation of the Gegenschein has been based on certain properties of the straight line solutions, and some recently discovered planetoids which make an approximate equilateral triangle with the sun and Jupiter have directed attention again to the triangle solutions.

About 1890 Poincaré turned his attention to the problem of three bodies. He brought to bear upon it a fertility of resource and a knowledge of modern mathematics not approached in any other writer. The results he obtained are of the highest importance theoretically, and will be equally important practically when they shall be elaborated in a form suitable for numerical applications. In his hands celestial mechanics has been entirely recast.

The point of interest in the present connection is that Poincaré proved the existence of a great variety of exact (periodic) solutions of the problem of three bodies. Their properties were very fully specified, and though the coördinates in all cases are given by infinite series, for suitable values of the masses and other constants upon which they depend they may be computed with any desired degree of precision. Since Poincaré paved the way many other writers have proved the existence and showed how to determine many classes of periodic orbits. The theory is one of many symmetries and beauties and has the finish of the theory of elliptic functions. Besides the pleasure that comes from working in a domain where strict logic prevails and where wonderful harmonies appear on every hand, one has the satisfaction of knowing that, as Poincaré has said, these solutions at the present time constitute the single breach into a region hitherto considered inaccessible. He meant by this that at present there is no hope of being able to describe the motion of three or more mutually attracting bodies for indefinite time, except through these exact solutions, or by showing that they are limiting cases. In spite of his great genius Poincaré had to leave certain of the most important questions along this line altogether unanswered.

We now come to the consideration of an altogether different order of ideas. The culmination of this line of argument is the work of Sundman. It is properly called the "culmination" because it was started in a purely formal way by Euler, received in certain important respects its logical foundation by Cauchy and Weierstrass, was carried an important step in another direction by Levi-Civita and Bisconcini, and has been completed by Sundman.

The differential equations, based on the laws of motion and the law of gravitation, which the motion of the three bodies m_1, m_2, and m_3, satisfy are:

$$(1)\quad \begin{cases} \dfrac{d^2x_1}{dt^2} = -k^2m_2\dfrac{(x_1-x_2)}{r_{12}^3} - k^2m_3\dfrac{(x_1-x_3)}{r_{13}^3} \\ \dfrac{d^2y_1}{dt^2} = -k^2m_2\dfrac{(y_1-y_2)}{r_{12}^3} - k^2m_3\dfrac{(y_1-y_3)}{r_{13}^3} \\ \dfrac{d^2z_1}{dt^2} = -k^2m_2\dfrac{(z_1-z_2)}{r_{12}^3} - k^2m_3\dfrac{(z_1-z_3)}{r_{13}^3} \end{cases}$$

and six similar equations obtained by cyclical permutations of the subscripts. The distances $m_1\,m_2$, $m_2\,m_3$, and $m_3\,m_1$ are represented by r_{12}, r_{23}, and r_{13} respectively. The characteristic property of these differential equations is that their right members are analytic functions of $x_1, x_2, \ldots, z_3$; that is, they can be expanded as converging power series in x_1-a_1, x_2-a_2, x_3-a_3, y_1-b_1, ..., z_3-c_3 provided r_{12}, r_{23}, and r_{13} are all distinct from zero if $x_1=a_1$, $x_2=a_2$, ..., $z_3=c_3$. If the $a_1, \ldots, c_3$ are the initial values of $x_1, \ldots, z_3$ this condition is satisfied unless two or more of the bodies are in collision at the origin of time. This case will be excluded except when it is explicitly assumed.

Suppose the r_{ij} are all distinct from zero at $t=0$. Then the solutions of equations (1) can be expanded as power series in t of the form

$$(2)\quad x_1 = a_1 + \left(\frac{dx_1}{dt}\right)_0 t + \frac{1}{2}\left(\frac{d^2x_1}{dt^2}\right)_0 t^2 + \ldots + \frac{1}{n!}\left(\frac{d^nx_1}{dt^n}\right)_0 t^n + \ldots$$

and similar equations for $x_2, \ldots, z_3$. The first derivatives are arbitrary. The second derivatives can be replaced by the right members of equations (1). The third derivatives can be obtained from the first derivatives of equations (1) whose right members will depend only on the a_i, b_i, c_i and the first derivatives of $x_1, \ldots, z_3$. This process can be continued and all the coefficients of the series (2) can be expressed in terms of the a_i, b_i, c_i and the first derivatives of $x_1 \ldots, z_3$. The work gets rather complicated when it is carried far, but it is actually used in some problems, particularly in the determination of orbits, and has been a known process since the days of Euler.

The critical question is whether equations (2) converge under any circumstances, and if so what they are. It was proved by Cauchy approximately one hundred years after the time of Euler that, under the hypothesis on (1) which have been specified, equations (2) converge for values of t which are not too great. In fact, a limit was defined within which they certainly converge, but it was not the largest limit for which they are valid. The largest limit is as yet unknown. It was later shown by Briot and Bouquet that in the special case of one equation, and still later by Picard and Painlevé in the general case, that the solution (2) is the only one taking the specified unital values which is continuous.

Since the series (2) converge and are unique they constitute a perfectly rigorous and general solution of the problem of three bodies. They show that the coördinates are analytic functions of the time, but not much else. The fact is that such an infinite variety of functions are representible as converging power series that to say a function is developable in this way does very little to characterize it. The known properties of the solution (2) do not determine whether or not the motion is periodic, whether or not there will be collisions or infinite separation of the bodies, or any of the other things, depending upon a considerable interval of time, which one might wish to know. They would not enable one to compute the position of a body except for a very short time, and a theory of the motion of the planets or of the moon built up in this way would be of no value whatever. While the series (2) constitute a general solution of the problem it is an essentially useless one.

The question arises whether the solution (2) cannot be modified so as to avoid the limitations to which it is subject. In order to discuss this question it is necessary to make some remarks on what it is that limits the realm of convergence of power series. It was proved about ninety years ago by Abel that the domain of convergence of a power series is a circle. That is, if t is regarded as the complex variable

$$t = \rho + \sqrt{-1}\,\sigma,$$

where ρ and σ are real, the values of t, i. e. of ρ and σ, for which the power series converges all lie in a circle. If the circle is of finite radius the series does not converge for any value of t belonging to a point outside of the circle. On the circle of convergence there is at least one so-called singular point of the function. It may be desired in practice to consider the function only for real values of t, but since the singular point which limits the domain of convergence may be complex, it is clear that in the discussion it is necessary to suppose that t is capable of taking all real and complex values. This is one of the reasons why the theory of complex variables has become so important in physical problems where only real values of the variables are ordinarily used in the applications.

Some examples will make the matter clear. The function $\dfrac{1}{1-t}$ when expanded as a power series in t converges only if t is less than unity in numerical value. This is known from the properties of the geometric series. But the reason from the present point of view is because the function becomes infinite for $t=1$. Now consider $\dfrac{1}{1+t^2}$ which can be expanded as a power series in t^2, for example by the binominal theorem. This function is finite for all real values of t, but the convergence of the series does not hold for all real values of t. The function is infinite for $t=\pm\sqrt{-1}$ because for this value of t the denominator vanishes. Since these points are distant unity from the origin the expansion of this function also converges only in a circle whose radius is unity. If the denominator is a polynomial the radius of convergence of its expansion is the distance from the origin to its nearest zero. But the function $(1-t)^{1/3}$ can be expanded as a power series in t, and since it is finite for all values of t it might be supposed that the radius of its circle of convergence is infinite. But this conclusion is incorrect. The function has three cube roots and they are all equal for $t=1$. Such a point is called a "branch-point" and is one of the singular points which limit the circle of convergence of a function. The circle of convergence of this function has the radius unity also. There are other types of singular points and mixtures of all types.

Now return to the consideration of the problem of three bodies. One of the difficulties is determining the location of the singular points of the solution. At present there is no general method of finding them. If they could be located a series of polynomials could be built up out of the power series, by a method due to Mittag-Leffler, which would converge for all finite values of t except those lying along certain lines joining the singular points to infinity. If there were no singular points for real values of t, this would constitute a general solution of the problem, valid for all real values of t. It must be admitted, however, that its complexity would be such that it would have no practical value. If it could be proved that for any specified initial conditions there is a strip of finite width along the real axis which contains no singular points, then t could be expressed in terms of another variable τ by a well-known formula which would transform the strip into a circle. The solution would be expansible as a power series in τ which would converge for values corresponding to the real values of t. This again would constitute a complete solution of the problem for the specified initial conditions, but it would also be of no practical value. And what is still worse, there is no general method of determining when a strip of finite width having no singular points, exists.

In the examples it was seen that there are several kinds of singular points. The question arises what kind of singular points occur in the solution of the problem of three bodies. Painlevé proved that there are singular points in the solution only for a collision of two or more of the bodies in real or complex time. In considering a collision the bodies are supposed to be simply mathematical points. If this statement for complex time does not have a definite physical meaning, nevertheless it is perfectly clear and straightforward mathematically. Levi-Civita proved in a characteristically elegant and profound memoir that in the restricted problem of three bodies (i. e. one infinitesimal and the finite bodies describing circles) the only singularities are branch points where three branches coincide. In this respect the functions are like the last example above, but in other respects they are immensely more complicated. Bisconcini extended Levi-Civita's results to the case where all three bodies are finite, but he was compelled to make one assumption which seemed reasonable. Sundman proved that the assumption is true. Strictly speaking the results of Levi-Civita hold in general without important modification only when not all three constants of the integrals of areas are zero. When they are zero Sundman has proved that the three bodies simultaneously collide, and as they approach collision they approach the equilateral triangle configuration of Lagrange.

Now consider the case where not all three of the constants of the integrals of areas are zero. This is of course the general case and is the one treated by Sundman in his memoir in *Acta Mathematica*. He defines a variable u, following Levi-Civita, in terms of which the coördinates and t can be expressed as power series, whether or not the bodies are in collision. He then defines a new independent variable w having the desirable properties of u and certain very important additional ones. When expressed in terms of it the solution for arbitrary initial conditions, with the exception of the single restriction that not all three of the constants of the areas integrals shall be zero, has no singularities in a strip of finite width along the real axis which corresponds in a one-to-one, finite-to-finite, way with the variable t. When the strip is transformed to a circle by introducing the new independent variable τ, as described above, the solutions

converge for values of τ corresponding to all the real values of t. Moreover, the coefficients of these series can be determined from the original differential equations. Hence the problem is theoretically solved. The conjecture which has sometimes appeared in popular books, that the problem of three bodies could be solved only when new functions were discovered, has thus been shown to be incorrect—power series are entirely adequate.

The work of Sundman is of the highest excellence from the mathematical point of view, but astronomers will wish to know about its practical value. On this point, the report must be unfavorable. Practically it has all the defects of (2), except the limitation on the range of validity. It gives no properties of the motion, no answer to the questions the astronomer raises, and there is no hope of its being practically applied. The problem of three bodies, in many respects which have not been elaborated here, still challenges mathematicians, and there is little prospect of its being soon finished.

Some Fallacies About the Gasoline Engine*

By E. W. Fraser

It is commony accepted by many people, that if you raise the compression pressure, you must increase the power given off by the engine. While this may be true to some extent in relation to engines of early make, and having low compression pressures, say in the region of 60 to 80 pounds per square inch, it is rarely true in the case of modern engines having compression pressure in the region of 80 to 120 pounds per square inch. It is not compression pressure so much as mean effective pressure that tells as a power-producer, and it is far better to increase this latter by increasing the mixture strength than by lowering cylinders or placing aluminium discs on piston-heads, or other nostrums too often recommended in the amateur engineering press by writers who should know better. Two sets of figures taken from a contribution to *Engineering* of October 15th, 1909, by Mr. Tookey, will be given as part proof of the above statements. In one case, the compression pressure was 222, and the mean effective pressure 86, and in the other case the compression pressure was 114, and the mean effective pressure 129 pounds per square inch. It is, therefore, fairly obvious that if abnormal compression pressures meant abnormal horse-power, otherwise mean effective pressure, then the experiment in which the engine had 222 pounds compression pressure should have shown a higher mean effective pressure than it did. Now as to ignition. There are many who still hold that a first-class coil and battery is as good as anything, and that much extra efficiency is gained by using two sparking-plugs, and firing the charge simultaneously from two places in the combustion-chamber. As to the coil, it is not, in my opinion, of much use on engines at speeds of 2,000 to 4,500 revolutions per minute. The series plugs were also an absolute failure, no difference being observed at any speed under load from 1,800 to 3,000, whether one set of plugs were used or two. The highest-class magneto and the best procurable plugs and wires seems to be the only thing that will stand up to speeds up to 4,500, and horse-power in the region of 100. Above these speeds and powers the writer has had little or no experience. However, I may say that these views are held by no less an authority than Mr. L. H. Pomeroy, whose name is well known in connection with the development of the modern high-speed engine. Now for a few mechanical fallacies. An engine had been thoroughly over-hauled, and all bearings fitted without shake, valves a good fit in their guides, pistons held compression well, and yet, after running five minutes, it seized up. Why? Because it was too well fitted. Crank-pins and journals expanded, as did pistons and valves under the heat generated by a speed of 2,500 revolutions per minute, and the oil being squeezed out from the bearing surfaces, they seized. Therefore, do not have things too tight. The exact amount of slack allowable can only be determined by a knowledge of the metals used, and the speed at which it is desired to run the engine. A nickel-steel shaft, 1½ inches diameter, and running in high-grade white metal bearings, should have at least 0.003 slack if it is to run at over 2,000, and should then be fed with oil at 10 pounds per square inch pressure through a 3/16-inch pipe. A 3-inch cast-iron piston may have 0.004 slack, and still work well. Slack-piston knocks only develop after 0.006 clearance is reached. Now as to valve-grinding: the less of this you do, the better. Pull the engine over on compression, and listen at the induction-pipe. If you hear a hissing sound, it is the inlet leaking. If you hear it at the exhaust-pipe, it is the exhaust valve. If no sound is heard, let the valves rest; they will only be made worse, probably, if you meddle with them. Just at present there is somewhat of a mania for lightening reciprocating parts, such as pistons, and many think that by so doing they can increase the power given off by the engine. This is not so, as a moment's reflection will show. What does happen is that you get less strain on the gudgeon-pin, crank-pin, and connecting-rod, and less mechanical friction to be overcome. Also by using special shape pistons there is less area in contact with the cylinder walls, and, therefore, again, less friction to be absorbed by the available power. The fitting of such things is, however, best left to firms who are specialists in this class of work, and does not come within the scope of this paper. Now a few words as to procuring a good mixture. Many amateurs will tell you how they constructed a wick carbureter from a mustard-tin and some cotton-wool, while others swear by a tin of old cycle-balls, with the gasoline dripping down through them. Such carbureters are rarely economical and do not give the varying strength of mixtures for different speeds, while acceleration is a thing they know nothing of. The best way is to purchase the very best carbureter you can afford—not going by makers' advertisements (they *all* make the best), but rather noting what carbureters winners of Brooklands' and other events used, and get one of these.

This remark also applies to the magneto. Many of you may object that you do not possess multi-cylinder engines, or even a decent motor cycle, but have one of the stationary type, either vertical or horizontal. If they are above 1 horse-power, and by makers of repute, most of my foregoing remarks will hold good; but if they are the usual article advertised, and sold as ranging from ⅛ horse-power to ¾ horse-power, they are beyond redemption. I have seen and carefully examined one or two makes of this class of goods. The design, such as it is, is of the most antiquated gas-engine type, the material shoddy, and the workmanship beneath contempt. To bring such rubbishy things into line with modern gasoline-engine practice would inevitably fail. Certainly they are cheap. But to expect to get a ¾ brake horse-power engine complete for about $30 is one of the biggest fallacies I have mentioned to-night. One has only to have a most elementary knowledge of engineering practice to be able to find numberless faults. To such as have this type of engine I would say: Waste no more money on it than you can help, fit it with your most antiquated coil and battery, and a mustard-tin carbureter, get it running, and sell it before it breaks down, and then buy an engine.

* A paper read before the Society of Model and Experimental Engineers at a recent meeting.

The Manufacture of Vulcanized Fiber

In the manufacture of a product resembling vulcanized fiber, cotton and linen are exclusively employed as raw materials. The rags are very carefully sorted and before pulping are boiled with soda. Beating is then carried out in the beating engine until no remnant of the fabric is longer present; the fibers must in this case remain unshortened. The pulp is caused to run direct from the beater into a centrifugal machine, the drum of which is lined with metallic cloth; the soda solution is then flung out and the fragments of the fibers which are liable to cause trouble later on in the process are removed, these fragments after separation being collected. The washed pulp is thereupon mixed with a quantity of zinc chloride and is converted by hand or on machines into a loose or spongy pulp sheet.

According to *Papierfabrikant*, from which these notes are reproduced, the chemical treatment of the pulp sheet so obtained has for its object to swell the various fibers and to convert them into a colloidal condition. According to the desired quality, the fiber may be converted into this condition only at the surface of the sheet. Of various solvents, the greatest advantages are derived from zinc chloride because it is inodorous and 90 per cent can be recovered. On the sheet, which is then placed in a stoneware pan, is thereupon poured a zinc chloride solution of about 60 deg. Bé., and the pan is then covered with a glass plate. After some hours the excess lye is drained off and the sheet which appears viscous on its surface is uniformly strewn with a layer several millimeters thick of finely sifted zinc chloride.

When the powder has dissolved, the process can be accelerated by slight but very uniform heating. Regulation of the heat is best obtained in an electrically-heated muffle furnace. The front wall of the furnace consists of a thick glass plate and the progress of the process can be followed by the aid of an incandescent lamp mounted in the interior of the furnace, as also by means of several thermometers arranged at the furnace.

At the beginning the temperature should amount at most to 40 deg. Cent.; thereupon the temperature is allowed to rise during one hour to 60 to 70 degrees. The surface of the mass gradually becomes vitreous and the unevenness disappears, whereupon the pan is carefully removed from the furnace and covered with a glass plate until cool.

After removal of the glass plate the zinc chloride absorbs water from the air, the lye is poured off, and the pan is filled with water and allowed to stand for some hours. The sheet is then carefully removed from the pan, laid on the glass plate and set up over larger pans so that the solution can drain off. The sheet is thereupon watered while lying on lead-coated wire netting and is dried with the gradual application of heat, and if necessary *in vacuo*. The sheet, which is slightly wavy, is then, while cold, pressed out flat by application of strong pressure.

In this way is obtained a material which is pale yellow in color, is fairly transparent in centimeter sheets and is not softened by heat, but on the other hand, always becomes harder. It is quite as elastic as a solid hard rubber, its breaking stress is considerably higher, and it is a perfect substitute for vulcanized fiber. The further treatment of this material is the same as in the case of natural horn.—*Paper.*

Aeroplane for High-Tension Line Patrol

We read in *Science Conspectus* that a California transmission company patrols its high-tension lines leading out of Oakland in an aeroplane. A lineman equipped with repair apparatus will ride with the aviator, and the pair will take trips twice a week. The headquarters of this novel inspection crew are to be established at Sacramento.

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